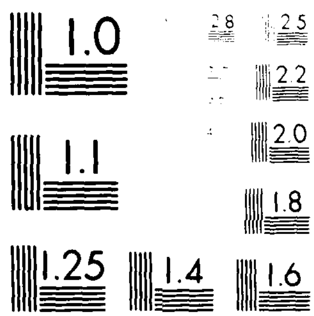
AD-A116 208 WEAPONS SYSTEMS RESEARCH LAB ADELAIDE (AUSTRALIA) F/G 8/10
TECHNIQUES FOR THE ANALYSIS OF EXPENDABLE BATHYTHERMOGRAPH (XBT--ETC(U)
SEP 81 P G MARSHALLSAY, S M BALL
UNCLASSIFIED WSRL-0229-TM NL

1 OF 1
AD A
116208

END
DATE
FILMED
07-82
DTIC


1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

(12)

WSRL-0229-TM

AR-002-627

AD A116208

AUSTRALIA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS SYSTEMS RESEARCH LABORATORY

DEFENCE RESEARCH CENTRE SALISBURY
SOUTH AUSTRALIA

TECHNICAL MEMORANDUM

WSRL-0229-TM

TECHNIQUES FOR THE ANALYSIS OF EXPENDABLE BATHYTHERMOGRAPH (XBT) DATA WITH APPLICATIONS TO THE SOUTH-WESTERN PACIFIC OCEAN

P.G. MARSHALLSAY and S.M. BALL

Technical Memoranda are of a tentative nature, representing the views of the author(s), and do not necessarily carry the authority of the Laboratory.

Approved for Public Release

SEPTEMBER 1981

COPY No.

AR-002-627

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS SYSTEMS RESEARCH LABORATORY

TECHNICAL MEMORANDUM

WSRL-0229-TM

TECHNIQUES FOR THE ANALYSIS OF EXPENDABLE BATHYTHERMOGRAPH (XBT) DATA WITH APPLICATIONS TO THE SOUTH-WESTERN PACIFIC OCEAN

P.G. Marshallsay and S.M. Ball

S U M M A R Y

The expendable bathythermograph is a convenient and inexpensive tool for the measurement of ocean temperature structure. It does not measure salinity, but in many areas of the ocean it is reasonable to use standard temperature-salinity (T-S) curves to infer salinity from temperature measurements. T-S curves constructed from historical Nansen cast data are presented for 10° squares in the South-Western Pacific Ocean, covering the area from 15°S to 45°S, and from 150°E to 180°E. With a knowledge of both temperature and salinity structures a wide range of other parameters may be estimated, the most important of these being density, dynamic height and sound speed. Relationships for the computation of these and other properties of sea water are discussed, and computer programmes presented to calculate profiles of the relevant parameters from XBT data.

POSTAL ADDRESS: Chief Superintendent, Weapons Systems Research Laboratory, Box 2151, GPO, Adelaide, South Australia, 5001.

TABLE OF CONTENTS

	Page No.
1. INTRODUCTION	1
2. T-S CURVES FOR THE SOUTH-WESTERN PACIFIC OCEAN	2
3. THE PROPERTIES OF A COLUMN OF SEAWATER	4
3.1 Gravitational acceleration	5
3.2 The equation of state for seawater	5
3.3 Pressure	10
3.4 The speed of sound	10
3.5 Specific heat	13
3.6 Dynamic height anomaly	18
4. COMPUTER PROGRAMME ORGANISATION	19
4.1 Plotting options	20
4.2 Temperature/Depth data input	20
REFERENCES	23
APPENDIX I NANSEN CASTS USED TO DERIVE T-S CURVES	26
APPENDIX II CUBIC SPLINE COEFFICIENTS FOR THE T-S CURVES	28
APPENDIX III DENSITY PROFILES FOR THE SOUTH-WEST PACIFIC OCEAN	31
APPENDIX IV TABULATED VALUES OF SOME OCEANOGRAPHIC VARIABLES	32
IV.1 Salinity = 34 parts/thousand	32
IV.1.1 Specific volume ($cm^3.g^{-1}$)	32
IV.1.2 Isothermal compressibility ($bar^{-1}.10^6$)	32
IV.1.3 Thermal expansibility ($degrees^{-1}.10^6$)	33
IV.1.4 Specific heat, C_p ($j.g^{-1}.degrees^{-1}$)	33
IV.1.5 Sound speed ($m.s^{-1}$)	34
IV.2 Salinity = 35 parts/thousand	34
IV.2.1 Specific volume ($cm^3.g^{-1}$)	34
IV.2.2 Isothermal compressibility ($bar^{-1}.10^6$)	35
IV.2.3 Thermal expansibility ($degrees^{-1}.10^6$)	35
IV.2.4 Specific heat, C_p ($j.g^{-1}.degrees^{-1}$)	36
IV.2.5 Sound speed ($m.s^{-1}$)	36
IV.3 Salinity = 36 parts/thousand	37
IV.3.1 Specific volume ($cm^3.g^{-1}$)	37
IV.3.2 Isothermal compressibility ($bar^{-1}.10^6$)	37
IV.3.3 Thermal expansibility ($degrees^{-1}.10^6$)	38
IV.3.4 Specific heat, C_p ($j.g^{-1}.degrees^{-1}$)	38
IV.3.5 Sound speed ($m.s^{-1}$)	39

Page No.

APPENDIX V LISTING OF A FORTRAN IV PROGRAMME TO PROCESS XBT DATA 40

V.1 Main programme 40

V.2 Subroutine DSW1 43

V.3 Subroutine DSW1A 44

V.4 Subroutine DSW2 45

V.5 Subroutine PSW1 46

V.6 Function DDER 48

V.7 Subroutine SSSW1 48

V.8 Function SAL 50

V.9 Subroutine PLOT1 52

V.10 Subroutine LNGPLT (additional ENTRY ADDPLT) 54

APPENDIX VI SAMPLE PROGRAMME OUTPUT 57

APPENDIX VII SAMPLE CARD IMAGE INPUT FILE 58

APPENDIX VIII INPUT DATA FORMAT FOR AN XBT DATA POINT RECORD AS USED BY AODC 60

VIII.1 Input record format 60

VIII.2 BT instrument and grid code 62

VIII.3 Digitisation method, interval of digitisation, and Data treatment and storage codes 63

APPENDIX IX HARWELL SUBROUTINES USED BY THE DATA REDUCTION PROGRAMME 64

IX.1 Subroutine TB04AD 64

IX.2 Function TG01BD 65

IX.3 Function QG02AD 65

IX.4 Subroutine QG05AD 66

APPENDIX X CALCOMP PLOTTER ROUTINES USED BY THE DATA REDUCTION PROGRAMME 67

X.1 Subroutine PLOTS 67

X.2 Subroutine ENDPLT 67

Page No.

X.3 Subroutine ENDGR 67

X.4 Subroutine PLOT 67

X.5 Subroutine SYMBOL 68

X.6 Subroutine NUMBER 68

X.7 Subroutine LINE 69

LIST OF FIGURES

1. Locations of Nansen cast stations in the South-West Pacific Ocean

2. Temperature-salinity diagrams for the South-West Pacific Ocean constructed from historical Nansen cast data. The solid curves represent a least-squares cubic spline fit to the data (see text)

3. Temperature profiles constructed from Nansen casts made in the South-West Pacific Ocean. Points pertaining to the mixed layer have been edited out of the data base, and the data for each geographical area pooled

4. Profiles of σ_T versus depth constructed using the temperature profiles of figure 3 and corresponding salinity data. The solid curves represent a least-squares fit of equation (2)

5. XBT programme organisation - an overview

6. A sample "fourplot"

7. A sample "longplot"

8. WMO Code 3333 quadrant and 10° square numbering system

9. Modified Canadian 10° square subdivisions. All subdivisions of 10° squares are numbered identically regardless of quadrant of the globe

1. INTRODUCTION

The oceanographer is frequently confronted with the need to make extensive measurements of large-scale features in a scenario which may undergo significant changes in a relatively short span of time. In this situation the need for near-synoptic information covering the area of interest is obvious, and the delays inherent in the traditional techniques of making Nansen casts, or more recently conductivity-temperature-depth (CTD) surveys, which involve prolonged stoppages on-station may be highly undesirable, if not unacceptable. Against this background the expendable bathythermograph (XBT) has established itself over the past decade or so as an invaluable tool in the conduct of rapid oceanographic surveys, either supplementing or replacing the previously-mentioned techniques. The XBT briefly comprises a low-cost, weighted, finned projectile with a thermistor bead mounted in the nose, together with associated launching equipment and recording instrumentation. The thermistor forms one arm of a bridge, into which it is connected by several hundred meters of lightweight, insulated copper wire, which is spooled out as the projectile falls. The hydrodynamic characteristics of the projectile produce a known rate of descent, so that temperature may be recorded as a continuous function of depth. The value of the technique lies in the fact that measurements may be made in transit, and a given area may thus be surveyed in a considerably lesser time than would otherwise be possible.

A survey conducted using such techniques produces a near-synoptic picture of the temperature structure of the area under investigation. The rapidity and relatively low cost with which such a survey may be performed makes the optimal use of the accruing data as a means of inferring details of the distribution of dynamic height and sound speed, together with other properties of the ocean waters, highly desirable. Estimation of such properties requires however, that the corresponding salinity structures of the areas under study also be known. It has long been recognised that for most of the World's ocean waters a close relationship exists between temperature and salinity, and a number of investigators have examined the possibility of using this relationship to infer salinity from temperature measurements made using bathythermographs (BTs) and XBTs(refs.1 to 3). The results of such studies have been sufficiently encouraging to induce a large number of workers to adopt the use of temperature-salinity (T-S) curves derived either from Nansen or CTD surveys made concurrently with an XBT survey, or in the absence of such measurements, from historical data, as a standard means of processing XBT data to derive estimates of temperature and salinity-dependent oceanographic variables (see for instance, reference 4). Such temperature-salinity relationships tend to be applicable over relatively wide geographical areas, and, with the exception of the topmost tens of metres of the ocean, which are subject to seasonal and shorter term influences, to be substantially independent of depth. In a survey of available historical data for the Pacific Ocean between 20°S and 40°N, considered as being divided into 10° squares, Emery and Wert(ref.5) found the error in estimating dynamic height from temperature measurements augmented by salinities inferred using standard T-S relationships to exceed uncertainties in the measurements accruing from other causes in only about 25% of the areas considered. These they identified as being transition regions between different water masses. Flierl(ref.6) further considered the problem of reducing XBT measurements made in transition zones such as may be found on the boundaries of eddies, and derived a procedure for the processing of such data in conjunction with supplementary topical CTD measurements.

In the present study we address ourselves to the case where the use of standard T-S curves may be regarded as providing the desired accuracy and reliability, and discuss the derivation of profiles of properties of interest using such methods. A series of standard T-S curves for the South-West Pacific Ocean between 15°S and 45°S, and between 150°E and 180°E are developed from historical data, and their implementation as a basis for a computational scheme considered. Relationships for the computation of dynamic height and a variety of seawater properties dependent upon temperature, salinity and pressure are then presented. Finally, a series of computational routines to process XBT data to produce profiles of the previously introduced properties are listed and described.

2. T-S CURVES FOR THE SOUTH-WESTERN PACIFIC OCEAN

For the analysis of XBT data from the Tasman Sea, the area from 15°S to 45°S, and from 150°E to 180°E was divided into 10° squares. The location and labelling of the squares is shown in figure 1. Representative standard T-S curves were then constructed using historic Nansen cast data originating from CS..O and RANRL cruises. The distribution of the available data over the area of interest varied enormously; the region immediately beyond Sydney Harbour was represented by an extremely heavy concentration of data, while the available data for some of the more remote squares was, by comparison, sparse. Approximately twelve Nansen cast profiles were chosen from each square to form a data base for further processing. The representative Nansen casts were selected so as to be more-or-less evenly distributed over their respective areas. In addition, since it was desired to pool all selected data for a particular square without regard to season, wherever possible the casts were selected so that approximately three profiles from each season were available for a given square. Details of the Nansen casts selected are reproduced in Appendix I, and the locations of the casts shown on figure 1.

T-S curves constructed using the pooled Nansen cast data points for each area are reproduced, without identification of the individual soundings, in figure 2. Data points from within the mixed layer had previously been edited out of the data base by hand. The comparatively small size of our data base precluded the possibility of performing any pre-processing quality control of the type used by Emery and Wert(ref.5), and by Pearce and Hamon(ref.7). Nevertheless, the data points selected are seen to define a series of T-S curves which are 'tight' in the sense of reference 2. As expected, scatter is largest at the highest temperatures, corresponding to the upper layers of the ocean.

For computational purposes it is desired that the T-S curves of figure 2 be represented by a series of functions in a manner which is in some sense optimal. In the first instance it was attempted to fit fourth-order polynomials to the data. Here, as in reference 7, it was found impossible to faithfully represent the T-S curves for this geographical area by low-order polynomials. The problems become most evident in the case of those areas such as B1 and C1 in which the T-S curves exhibit a curious 'hook' close to the minimum temperature. In attempting to provide an optimal fit through this section of the data, the polynomial approximations were found to consistently overestimate the deepwater salinity minima. In order to overcome this problem, Pearce and Hamon omitted all points representing temperatures lower than 2.5°C from the polynomial fitting process. We chose instead to retain all data points, and to represent the curves using cubic splines fitted in the least-squares sense. This was done using subroutine

VC03A from the Harwell Subroutine Library(ref.8). This employs a least-squares cubic-spline fitting algorithm which selects its own level of smoothing, and chooses its own knot points to span the domain over which the function is defined by the available data. The fitted curves correspond to the solid lines in figure 2, and are seen to comprise an excellent representation of the data, particularly at the low temperature end of the domain. The cubic spline coefficients are listed in Appendix II.

Further appreciation for the relevance of the T-S relationships may be gained by considering the temperature structure of an ocean water column. For this purpose the Nansen cast temperature data have been plotted against depth for each area in figure 3. These provide some indication of the depth appropriate to a specific point on the T-S curves. It should be borne in mind however that what is postulated is not an unvarying temperature-depth relationship, but a unique temperature-salinity relationship. Thus, although the water at a given depth within a particular 10° square may show considerable variation, the salinity corresponding to a given temperature may, to a close approximation, be regarded as being specified by the appropriate T-S curve without regard to the depth or time of the year at which the sample was taken. In general, these comments are true for all but the uppermost layers of the ocean. For instance, the T-S relationship for area A1 is seen to be very 'tight' indeed for temperatures below about 20°C. Higher temperatures than this are, on the whole, confined to the uppermost 200 m of the ocean, although it will be noted that at say, 500 m, temperature fluctuations over a 3° span are evident, within a temperature range corresponding to a 'tight' portion of the T-S curve.

The confidence with which the standard T-S curves may be used to reduce data from the uppermost layers of the ocean will depend in part upon the use which is to be made of the results. Thus, A.F. Pearce (personal communication) suggests that, if the results are to be used to estimate dynamic height, then there is little point in attempting to correct the results for surface effects, since the uppermost layers of the ocean contribute little to the dynamic height. Andrews(ref.3) further regards the salinity obtained from a T-S relationship as comprising a second-order correction to the estimates of the physical properties of seawater. He does however, propose a correction technique for surface effects which may be used if surface salinity has been measured, and which comprises a technique for interpolation between the surface salinity and the deep-sea salinity inferred from a standard T-S curve. Thus, if the depth D_m is selected as the depth at which the thermal gradient evaluated over a 10 m interval of depth is a maximum, and L is the depth of the mixed layer, defined as the depth at which the temperature has fallen to 98.5% of the average value above that point, then Andrews proposes that the salinity in the upper layers of the ocean may be found according to the equations

$$S(z) = S_0, \qquad 0 \leqq z \leqq L, \qquad (1(a))$$

$$S(z) = (z - L)\frac{S(T(z)) - S_0}{1.5D_m - L} + S_0, \qquad L \leqq z \leqq 1.5D_m, \qquad (1(b))$$

and

$$S(z) = S(T(z)), \qquad z \geq 1.5D_m. \qquad (1(c))$$

where S_0 is the surface salinity, which is assumed to remain constant through the mixed layer.

Using the measurements of temperature and salinity from Nansen cast data, the corresponding one-atmosphere densities have also been computed using the equation of state of seawater as derived by Chen and Millero(ref.9). The data are plotted by area in figure 4, where the one-atmosphere density is expressed in the familiar sigma-t form(ref.10,11):

$$\sigma_T = 1000(\rho^0 - 1) \ (g.cm.^{-3}.10^{-3}) \qquad (2)$$

where ρ^0 is the one-atmosphere expressed in $g.cm^{-3}$. Andrews(ref.12) has proposed that the density structure in the Tasman Sea may be approximated by a relationship of the form

$$\sigma_T = \rho_0 + d\rho[1 - 1/(1 - z/D)] \qquad (3)$$

where the parameters ρ_0, $d\rho$ and D remain to be specified for a given area. Optimum values for these parameters were computed using a nonlinear least-squares function fitting subroutine (VB01AD) from the Harwell Subroutine Library(ref.8). In order to remove bias introduced by the concentration of data points in the upper layers of the ocean, it was found necessary to weight the data samples according to depth so that the correct behaviour was approached in the deep ocean. Each data point was multiplied by a weighting factor determined as

$$W = 1000(z/5000)^n \qquad (4)$$

where the exponent n was chosen by eye to give the desired behaviour for each area. Values of the parameter so computed, together with the weighting exponents, are listed in Appendix III. The resulting density-depth relationships are shown by the solid curves in figure 4.

3. THE PROPERTIES OF A COLUMN OF SEAWATER

Given that the temperature and salinity profiles for a column of seawater are known, then by invoking suitable relationships it is possible to estimate a large number of the physical properties of the seawater column. A number of such relationships are introduced and discussed in the present section. The intention has been to select relationships which offer a high degree of precision and accuracy and, wherever possible, have wide acceptance among the scientific community. The discussion presupposes the incorporation of the techniques and relationships described into a digital computational scheme. In many places therefore, a degree of sophistication and complexity has been

adopted which would be unacceptable to a user without computing facilities. Tables of the properties of seawater at selected values of temperature, pressure and salinity, computed using the relationships derived below, are given in Appendix IV.

3.1 Gravitational acceleration

The gravitational acceleration at sea-level may be regarded as a function of geographical latitude only, and is given by the expression(ref.13):

$$g_0 = 9.78049(1 + 0.0052884\sin^2\phi - 0.0000059\sin^2 2\phi) \qquad (5)$$

where ϕ is the latitude and g_0 is given in units of $m.s^{-2}$. If z represents depth (in metres) measured positive downwards from the ocean surface, then a correction may be made to account for departure from the ocean surface:

$$g = g_0(1 + 2.26\times10^{-7} z) \qquad (6)$$

3.2 The equation of state for seawater

The equation of state for seawater, which expresses specific volume as a function of pressure, salinity and temperature, has been the subject of extensive investigation in recent years. A critical review of past studies, and various forms of the equation of state, is contained in reference 14. At the present time, the introduction of a new standard equation of state is imminent(ref.15), the format of the equation of state following that of previous expressions developed in references 9 and 14. The computation of specific volume given temperature, pressure and salinity may be seen as a three-stage process. Firstly, the density of pure water is computed from the specified temperature. The perturbation to the density introduced by the presence of salinity is then computed. Chen and Millero(ref.14) have pointed out that it is advantageous from the point of view of estuarine and groundwater studies to consider pure water as infinitely diluted seawater in this manner, rather than deriving a one-atmosphere equation of state for seawater having validity over the limited range of salinities which may be encountered in the deep ocean. Finally, the specific volume at pressure may be computed from the density at one atmosphere. In the new equation of state, the second-order bulk secant modulus equation is used for this purpose. That is,

$$K = PV^0/(V^0 - V^P) = K^0 + AP + BP^2 \qquad (7)$$

where K is the secant bulk modulus at applied pressure P (bars), K^0 is the secant bulk modulus at one atmosphere (P=0), V^0 is the specific volume ($cm^3.g^{-1}$) at atmospheric pressure, and V^P is the specific volume at pressure P. A and B are adjustable parameters. As of April 1980 (the date of publication of reference 15), the one-atmosphere equation of state remained to be finalised.*

* Note added in press. Since completion of the work reported herein, a new international standard one-atmosphere equation of state for seawater has appeared in the literature. Details will be found in reference 26.

Recommendations for the computation of K^0, A and B in equation (7) had previously been proposed by the Joint Panel on Oceanographic Tables and Standards, these being published in reference 16. This source would appear however, to contain typographical errors, since computations with the expressions contained therein failed to reproduce the results of references 9 and 14 to within the accuracy stated in reference 16. As an interim measure therefore, pending the publication of the new standard equation of state in more positive form, the sound-speed derived equation of state of Chen and Millero(ref.14) has been adapted. There,

$$K^0 = K^0_w + aS + bS^{1.5} \tag{7(a)}$$

$$A = A_w + cS + dS^{1.5} \tag{7(b)}$$

$$B = B_w + eS \tag{7(c)}$$

where the salinity S is in parts/thousand, and the subscript w refers to pure water. The parameters a, b, c, d and e are temperature dependent and given by,

$$a = 53.751 - 0.4607T + 7.030x10^{-3}T^2 - 5.107x10^{-5}T^3 \tag{8}$$

$$b = 0.2322 - 4.838x10^{-3}T \tag{9}$$

$$c = 4.692x10^{-3} - 8.387x10^{-5}T + 4.68x10^{-7}T^2 \tag{10}$$

$$d = -1.332x10^{-4} \tag{11}$$

$$e = -1.412x10^{-6} + 9.006x10^{-8}T - 1.551x10^{-9}T^2 \tag{12}$$

where T is the temperature in degrees centigrade. The equation of state for pure water derives from the work of Chen, Fine and Millero(ref.17). The pure water density at specified temperature and atmospheric pressure, and associated pressure correction parameters are computed using,

$$\rho_w^0 = 0.9998395 + 6.7914\times10^{-5}T - 9.0894\times10^{-6}T^2$$

$$+ 1.0171\times10^{-7}T^3 - 1.2846\times10^{-9}T^4$$

$$+ 1.1592\times10^{-11}T^5 - 5.0125\times10^{-14}T^6 \qquad (13)$$

$$K_w^0 = 19652.17 + 148.183T - 2.29995T^2 - 0.012810T^3$$

$$- 4.91564\times10^{-5}T^4 + 1.03553\times10^{-7}T^5 \qquad (14)$$

$$A_w = 3.26138 + 5.223\times10^{-4}T + 1.324\times10^{-4}T^2$$

$$- 7.655\times10^{-7}T^3 + 8.584\times10^{-10}T^4 \qquad (15)$$

$$B_w = 7.2061\times10^{-5} - 5.8948\times10^{-6}T + 8.699\times10^{-8}T^2$$

$$- 1.010\times10^{-9}T^3 + 4.322\times10^{-12}T^4 \qquad (16)$$

where ρ_w^0 is the one atmosphere density for pure water (cm^3g^{-1}), defining the specific volume,

$$V_w^0 = 1/\rho_w^0 \qquad (17)$$

The perturbation to be applied to ρ_w^0 to evaluate the density of seawater at one atmosphere pressure (ρ_w^0) derives from the work of Millero, Gonzalez and Ward(ref.18).

$$\rho^0 - \rho_w^0 = (8.25917\times10^{-4} - 4.4490\times10^{-6}T + 1.0485\times10^{-7}T^2$$

$$- 1.2580\times10^{-9}T^3 + 3.315\times10^{-12}T^4)S +$$

$$(-6.33761\times10^{-6} + 2.8441\times10^{-7}T - 1.6871\times10^{-8}T^2$$

$$+ 2.83258\times10^{-10}T^3)S^{1.5} +$$

$$(5.4705\times10^{-7} - 1.97975\times10^{-8}T + 1.6641\times10^{-9}T^2$$

$$- 3.1203\times10^{-11}T^3)S^2 \qquad (18)$$

and

$$V^0 = 1/\rho^0 \qquad (19)$$

The equation of state of seawater contained in equations (7 to 19) may be used to compute specific volume to an accuracy of ($\pm10\times10^{-6}$ $cm^3.g^{-1}$) over *the range of 0 to 40 parts/thousand in salinity,* 0 to 40^{0}C *and* 0 to 1000 bars. In addition, the equation of state can be used to determine isothermal compressibility to an accuracy of $\pm0.03\times10^{-6}$ bar^{-1} and thermal expansibility to an accuracy of $\pm2\times10^{-6}$ $degrees^{-1}$ over the same range of salinity, temperature and pressure.

The isothermal compressibility, which finds application in the determination of seawater density from in situ measurements, and in the determination of sound speed(ref.19), is defined as,

$$\beta \equiv -\frac{1}{V^P}(\partial V^P/\partial P)_T \qquad (20)$$

and may be determined from equation (7):

$$\beta = \frac{V^0(K^0 - BP^2)}{V^P(K^0 + AP + BP^2)^2} \qquad (21)$$

Similarly, the expansibility of seawater,

$$\alpha \equiv \frac{1}{V^P}(\partial V^P/\partial T)_P \tag{22}$$

can be determined as

$$\alpha = \frac{1}{V^P}(\partial V/\partial T)^0 - \frac{P(\partial V/\partial T)^0}{V^P(K^0 + AP + BP^2)}$$

$$+ PV^0\frac{(\partial K^0/\partial T)_P + P(\partial A/\partial T)_P + P^2(\partial B/\partial T)_P}{V^P(K^0 + AP + BP^2)^2} \tag{23}$$

wherein the derivatives,

$$(\partial V/\partial T)^0 = -(V^0)^2(\partial \rho/\partial T)^0 \tag{23(a)}$$

$$\begin{aligned}(\partial \rho/\partial t)^0 = {} & 6.7914\times10^{-5} - 1.81788\times10^{-5}T \\ & + 3.0513\times10^{-7}T^2 - 5.1384\times10^{-9}T^3 \\ & + 5.796\times10^{-11}T^4 - 3.0075\times10^{-13}T^5 \\ & + (-4.4490\times10^{-6} + 2.097\times10^{-7}T \\ & \quad - 3.774\times10^{-9}T^2 + 1.326\times10^{-11}T^3)S \\ & + (2.8441\times10^{-7} - 3.3742\times10^{-8}T \\ & \quad + 8.49774\times10^{-10}T^2)S^{1.5} + (-1.97975\times10^{-8} \\ & \quad + 3.3282\times10^{-9}T - 9.3609\times10^{-11}T^2)S^2\end{aligned} \tag{23(b)}$$

$$(\partial K^0/\partial T)_P = 148.183 - 4.5999T + 3.843\times10^{-2}T^2$$
$$- 1.966256\times10^{-4}T^3 + 5.17765\times10^{-7}T^4$$
$$+ (-0.4607 + 1.406\times10^{-2}T - 1.5321\times10^{-4}T^2)S$$
$$+ (-4.838\times10^{-3})S^{1.5} \qquad (23(c))$$

$$(\partial A/\partial T)_P = 5.223\times10^{-4} + 2.648\times10^{-4}T - 2.2965\times10^{-6}T^2$$
$$+ 3.4336\times10^{-9}T^3 + (-8.387\times10^{-5} + 9.36\times10^{-7}T)S \qquad (23(d))$$

$$(\partial B/\partial T)_P = -5.8948\times10^{-6} + 1.7398\times10^{-7}T - 3.03\times10^{-9}T^2$$
$$+ 1.7288\times10^{-11}T^3 + (9.006\times10^{-8} - 3.102\times10^{-9}T)S \qquad (23(e))$$

3.3 Pressure

Employing the customary units as detailed in Sections 3.1 and 3.2 above, the pressure at depth Z (metres), measured positive downwards, may be found by the relationship,

$$P = 10^{-2}\int_0^Z g\rho dz \qquad (24)$$

Using the one-atmosphere density profile computed using equations (13) and (18) as a first approximation to ρ, a cubic spline is fitted through the recorded values of the product $g(z).\rho(z)$ using the Harwell Subroutine TB04AD(ref.8). The cubic spline is integrated between the surface and the appropriate depths using Harwell Subroutine QG02AD to give a first approximation to the pressure profile using equation (24). Most recent estimates of the density and pressure profiles are then used to iteratively update one another.

3.4 The speed of sound

The speed of sound U, in a compressible medium is defined by the equation,

$$1/U^2 = (\partial\rho/\partial P)_\theta = -1/V^2(\partial V/\partial P)_\theta \qquad (25)$$

where θ is the entropy. By expanding the right-hand side of equation (25), this may be rewritten as(ref.20),

$$1/U^2 = -1/V^2[(\partial V/\partial P)_T + T'(\partial V/\partial T)_P^2/C_p] \quad (26)$$

where, in this context, T' is understood to refer to absolute temperature. C_p is the specific heat at constant pressure, and $\beta \equiv -1/V\ (\partial V/\partial P)_T$ is the isothermal compressibility previously introduced (Section 3.2). Equation (26) then, comprises a unique relationship between sound speed, the equation of state and the specific heat, and forms the basis for methods of deriving the equation of state of water based on sound speed measurements. In equation (26), the first term is the dominant term, the thermodynamic term forming a second-order correction(ref.20). In this and the next section, expressions for the speed of sound in seawater, and the specific heat are presented.

The form of the relationship equation (26) establishes the desirability of achieving a level of consistency between the equation of state of seawater used in a particular study, and the sound speed equation. For this reason, the sound speed equation of Chen and Millero(ref.20) has been adopted in the present study, this forming the basis upon which their equation of state(ref.14) was derived. The sound speed equation consists of relationships for the speed of sound in pure water, and for the perturbations introduced by the presence of salinity. The composite system of equations is valid, as is the equation of state, over a range of 0 to 40 parts/thousand in salinity, 0 to 40^{o}C, and 0 to 1 000 bars in pressure. In the following, sound velocities are measured in m.s^{-1}, other variables being described in terms of their conventional units.

For pure water, the speed of sound is expressed as a function of temperature and pressure,

$$\begin{aligned} U_w = {} & 1402.388 + 5.03711T - 5.80852\times10^{-2}T^2 \\ & + 3.3420\times10^{-4}T^3 - 1.47800\times10^{-6}T^4 + 3.1464\times10^{-9}T^5 + \\ & (0.153563 + 6.8982\times10^{-4}T - 8.1788\times10^{-6}T^2 \\ & + 1.3621\times10^{-7}T^3 - 6.1185\times10^{-10}T^4)P + \\ & (3.1260\times10^{-5} - 1.7107\times10^{-6}T + 2.5974\times10^{-8}T^2 \\ & - 2.5335\times10^{-10}T^3 + 1.0405\times10^{-12}T^4)P^2 + \\ & (-9.7729\times10^{-9} + 3.8504\times10^{-10}T - 2.3643\times10^{-12}T^2)P^3 \end{aligned} \quad (27)$$

At atmospheric pressure, the differential between the speed of sound in pure water, and that in seawater is given by,

$$U_w - U_w^0 = (1.389 - 1.262\times10^{-2}T + 7.164\times10^{-5}T^2$$

$$+ 2.006\times10^{-6}T^3 - 3.21\times10^{-8}T^4)S +$$

$$(-1.922\times10^{-2} - 4.42\times10^{-5}T)S^{1.5} + 1.727\times10^{-3}S^2 \qquad (28)$$

From the above, the speed of sound in seawater under pressure may be found using the relationship,

$$(U^P - U_w^P) - (U^0 - U_w^0) = A_sS + B_sS^{1.5} + C_sS^2 \qquad (29)$$

where

$$A_s = (9.4742\times10^{-5} - 1.2580\times10^{-5}T - 6.4885\times10^{-8}T^2$$

$$+ 1.0507\times10^{-8}T^3 - 2.0122\times10^{-10}T^4)P +$$

$$(-3.9064\times10^{-7} + 9.1041\times10^{-9}T$$

$$- 1.6002\times10^{-10}T^2 + 7.988\times10^{-12}T^3)P^2 +$$

$$(1.100\times10^{-10} + 6.649\times10^{-12}T$$

$$- 3.389\times10^{-13}T^2)P^3 \qquad (29(a))$$

$$B_s = (7.3637\times10^{-5} + 1.7945\times10^{-7}T)P \qquad (29(b))$$

$$C_s = -7.9836\times10^{-6}P \qquad (29(c))$$

Finally, it should be mentioned that the work of Kroebel(ref.14, Annex 4) indicates that the presence of suspended particles may be a signficant additional factor in the determination of sound speed under operational conditions.

3.5 Specific heat

The specific heat of seawater is of importance, not only on account of its connection with the equation of state, and the sound speed equation, but in its own right, as a vital component in the thermodynamic make-up of the oceanic environment. As such, it is especially important in the computation of adiabatic lapse rates(refs.16,20). While a number of investigations of the specific heat of seawater at atmospheric pressure have been performed(refs.22,23), there are in existence no measurements of the specific heat of seawater at elevated pressures(ref.16). If however, the heat capacity can be evaluated at atmospheric pressure for specified temperature and salinity, then the specific heat at elevated pressure can be computed using the theoretical relationship(ref.24),

$$C_p = C_p^0 - T'\int_0^P (\partial^2 V/\partial T^2)_p dP \qquad (30)$$

where in this equation, T' is understood to be the absolute temperature.

Millero, Perron and Desnoyers(ref.23) give a relationship for the specific heat of seawater at atmospheric pressure,

$$C_p^0 = C_{pw}^0 + A_{cp}S + B_{cp}S^{1\cdot 5} \qquad (31)$$

where C_p^0 is the specific heat ($j.g^{-1}.deg^{-1}$) of seawater, and C_{pw}^0 is the specific heat of pure water at the same temperature, which may be found from,

$$C_{pw}^0 = 4.2174 - 3.720283\times10^{-3}T + 1.412855\times10^{-4}T^2$$

$$- 2.654387\times10^{-6}T^3 + 2.093236\times10^{-8}T^4 \qquad (31(a))$$

and the temperature dependent parameters A_{cp} and B_{cp} are given by,

$$A_{cp} = -7.644\times10^{-3} + 1.0727\times10^{-4}T - 1.38\times10^{-6}T^2 \qquad (31(b))$$

$$B_{cp} = 1.77\times10^{-4} - 4.08\times10^{-6}T + 5.35\times10^{-8}T^2 \qquad (31(c))$$

The pressure-dependent term of equation (30) may be derived from the equation of state of seawater (Section 3.2). That is, if we let,

$$I_2 \equiv \int_0^P (\partial^2 V/\partial T^2)_p dP,$$

then, equation (30) may be rewritten as,

$$C_p = C_p^0 - 0.1(T + 273.15)I_2 \tag{32}$$

where,

$$I_2 = P(\partial^2 V/\partial T^2)^0 + A_1 I_{11} + B_1 I_{21} + B_2 I_{22} + B_3 I_{23}$$
$$+ C_1 I_{31} + C_2 I_{32} + C_3 I_{33} + C_4 I_{34} + C_5 I_{35} \tag{33}$$

If we let

$$X = K^0 + AP + BP^2 \tag{34(a)}$$

and

$$q = 4K^0 B - A^2 \tag{34(b)}$$

then the integrals represented by the I terms above may be evaluated as follows:

$$I_{10} = \int_0^P \frac{dP}{X} = 2[\tan^{-1}\{(2BP+A)/\sqrt{q}\} - \tan^{-1}\{A/\sqrt{q}\}]/\sqrt{q}, \quad (q>0)$$

$$= \log[(2BP + A - \sqrt{-q})(A + \sqrt{-q})/\{(2BP + A + \sqrt{-q})(A - \sqrt{-q})\}]/\sqrt{-q}, \quad (q<0) \tag{34(c)}$$

$$I_{11} = \int_0^P \frac{P}{X} dP = \frac{1}{2B} \ln(X/K^0) - \frac{AI_{10}}{2B} \tag{34(d)}$$

$$I_{20} = \int_0^P \frac{dP}{X^2} = (2BP+A)/qX - A/qK^0 + 2BI_{10}/q \tag{34(e)}$$

$$I_{21} = \int_0^P \frac{P}{X^2} dP = -(1/X - 1/K^0)/2B - \frac{A}{2B} I_{20} \tag{34(f)}$$

$$I_{22} = \int_0^P \frac{P^2}{X^2} dP = -\frac{P}{BX} + \frac{K^0}{B} I_{20} \tag{34(g)}$$

$$I_{23} = \int_0^P \frac{P^3}{X^2} dP = \frac{1}{B} I_{11} - \frac{K^0}{B} I_{21} - \frac{A}{B} I_{22}$$

$$I_{30} = \int_0^P \frac{dP}{X^3} = \frac{2BP+A}{2qX^2} - \frac{A}{2q(K^0)^2} + \frac{3B}{q} I_{20} \tag{34(i)}$$

$$I_{31} = \int_0^P \frac{P}{X^3} dP = -(1/X^2 - 1/(K^0)^2)/4B - \frac{A}{2B} I_{30} \tag{34(j)}$$

$$I_{32} = \int_0^P \frac{P^2}{X^3} dP = -\frac{P}{3BX^2} - \frac{A}{3B} I_{31} + \frac{K^0}{3B} I_{30} \tag{34(k)}$$

$$I_{33} = \int_0^P \frac{P^3}{X^3} dP = -\frac{P^2}{2BX^2} + \frac{K^0}{B} I_{31} \tag{34(l)}$$

$$I_{34} = \int_0^P \frac{P^4}{X^3} dP = -\frac{P^3}{BX^2} + \frac{A}{B} I_{33} + \frac{3K^0}{B} I_{32} \tag{34(m)}$$

$$I_{35} = \int_0^P \frac{P^5}{X^3}\, dP = \frac{1}{B} I_{23} - \frac{K^0}{B} I_{33} - \frac{A}{B} I_{34} \qquad (34(n))$$

The coefficients in equation (34) are

$$A_1 = -(\partial^2 V/\partial T^2)^0 \qquad (35(a))$$

$$B_1 = 2(\partial V/\partial T)^0 (\partial K^0/\partial T)_P + V^0 (\partial^2 K^0/\partial T^2)_P \qquad (35(b))$$

$$B_2 = 2(\partial V/\partial T)^0 (\partial A/\partial T)_P + V^0 (\partial^2 A/\partial T^2)_P \qquad (35(c))$$

$$B_3 = 2(\partial V/\partial T)^0 (\partial B/\partial T)_P + V^0 (\partial^2 B/\partial T^2)_P \qquad (35(d))$$

$$C_1 = -2V^0 (\partial K^0/\partial T)^2_P \qquad (35(e))$$

$$C_2 = -4V^0 (\partial K^0/\partial T)_P (\partial A/\partial T)_P \qquad (35(f))$$

$$C_3 = -4V^0 (\partial K^0/\partial T)_P (\partial B/\partial T)_P - 2V^0 (\partial A/\partial T)^2_P \qquad (35(g))$$

$$C_4 = -4V^0 (\partial A/\partial T)_P (\partial B/\partial T)_P \qquad (35(h))$$

$$C_5 = -2V^0 (\partial B/\partial T)^2_P \qquad (35(i))$$

In the above, V^0 and the parameter K^0, A and B are given by equations (7) to (19). The first derivatives are computed according to

equations (23(a)) to 23(d)), and the second derivatives may be found using,

$$(\partial^2V/\partial T^2)^0 = -(V^0)^2(\partial^2\rho/\partial T^2)^0 + 2(V^0)^3[(\partial\rho/\partial T)^0]^2 \tag{36(a)}$$

$$\begin{aligned}(\partial^2\rho/\partial T^2)^0 = {} & -1.81788\times10^{-5} + 6.1026\times10^{-7}T - 1.54152\times10^{-8}T^2 \\ & + 2.3184\times10^{-10}T^3 - 1.50375\times10^{-12}T^4 \\ & + (2.097\times10^{-7} - 7.548\times10^{-9}T + 3.978\times10^{-11}T^2)S \\ & + (-3.3742\times10^{-8} + 1.699548\times10^{-9}T)S^{1\cdot5} \\ & + (3.3282\times10^{-9} - 1.87218\times10^{-10}T)S^2\end{aligned} \tag{36(b)}$$

$$\begin{aligned}(\partial^2K^0/\partial T^2)_P = {} & -4.5999 + 7.686\times10^{-2}T - 5.898768\times10^{-4}T^2 \\ & + 2.07106\times10^{-6}T^3 + (1.406\times10^{-2} - 3.0642\times10^{-4}T)S\end{aligned} \tag{36(c)}$$

$$\begin{aligned}(\partial^2A/\partial T^2)_P = {} & 2.648\times10^{-4} - 4.593\times10^{-6}T \\ & + 1.03008\times10^{-8}T^2 + 9.36\times10^{-7}S\end{aligned} \tag{36(d)}$$

$$\begin{aligned}(\partial^2B/\partial T^2)_P = {} & 1.7398\times10^{-7} - 6.06\times10^{-9}T \\ & + 5.1864\times10^{-11}T^2 - 3.102\times10^{-9}S\end{aligned} \tag{36(e)}$$

Computer evaluation of I_2 using equations (34) and (36) becomes inaccurate if $|B|$ becomes too small. As a check on the accuracy of the evaluation of

I_2, this integral was evaluated numerically. That is, the expression

$$(\partial^2V/\partial T^2)_P = (\partial^2V/\partial T^2)^0 - P(\partial V/\partial T)^0/X + PV^0X_1/X^2$$
$$+ PV^0X_2/X^2 - 2PV^0X_1^2/X^3 \qquad (37(a))$$

where

$$X_2 = (\partial K^0/\partial T)_P + P(\partial A/\partial T)_P + P^2(\partial B/\partial T)_P \qquad (37(b))$$

and

$$X_3 = (\partial^2K^0/\partial T^2)_P + P(\partial^2A/\partial T^2)_P + P^2(\partial^2B/\partial T^2)_P \qquad (37(c))$$

was integrated between the limits of 0 and P using an adaptive quadrature routine (Harwell subroutine QA05AD). Using double precision, the results computed using the two approaches were found to agree to five figures provided $|B|\geqq5\times10^{-6}$. The approach adopted for the computation of specific heat is a hybrid one; when $|B|\geqq5\times10^{-6}$, I_2 is evaluated analytically, while for $|B|<5\times10^{-6}$ the numerical scheme described above is used.

Even assuming that I_2 can be determined precisely, in the absence of measurements of specific heat of seawater at elevated pressures, and as a result of the shortage of measurements at one atmosphere also, the precision with which equations (29) and (30) may be used to estimate the specific heat of seawater remains in some doubt. Millero(ref.16, p 14) however, comments on accuracy of the one-atmosphere relationship for specific heat (equation (30)), and feels that it is sufficiently accurate for the computation of lapse rates, but possibly not for the definition of entropy. He states furthermore, that measurements of specific heat of pure water at elevated pressures do confirm the validity of using the thermodynamic relationship (equation (29)) to predict values at elevated pressures.

3.6 Dynamic height anomaly

Dynamic height anomaly provides a measure of the mass distribution in an ocean water column, its theoretical significance and use in the computation of geostrophic currents being described in most texts on oceanography (reference 13, chap 8; reference 14, chap 7). Dynamic height anomaly is defined as

$$\Delta D = \int_{P_0}^{P} \delta dP \qquad (38)$$

where P_0 is the pressure at the ocean surface (P_0=0), and P is the pressure at depth. δ is the specific volume anomaly,

$$\delta = V(S,T,P) - V(35,0,P) \tag{39}$$

which provides a measure of the departure of the specific volume of the ocean from that of a "standard ocean" having salinity, S=35 parts/thousand, temperature, t=0°C, and pressure P. In the appended computational package the integration of equation (39) is performed by fitting a cubic spline to δ=f(P) using the Harwell library subroutine TB04BD, and integrating the resulting piecewise-cubic polynomial using the Harwell subroutine QG02AD.

One of the fundamental problems associated with the computation of ocean currents using dynamic height anomaly is that of establishing the absolute current values; the dynamic method provides relative currents at different depths only. As an extension of the dynamic method* one may seek a regression of $D_{z1/z2}$ on $T_{z1/z2}$ where z2 is an assumed level of no motion, and z1 is some depth less than z2; $D_{z1/z2}$ is the dynamic height anomaly between z1 and z2, $T_{z1/z2}$ being the temperature difference over this depth increment. Now, if z2 is a level of no motion, it follows that within a certain geographical area t_{z2} will be approximately constant, and we may alternatively seek a regression of $D_{z1/z2}$ on T_{z1}. Provided z2-z1 is sufficiently small, it is reasonable to expect that $D_{z1/z2}$ will correlate closely with T_{z1}. Historically, for the East Australian Current area, z2 is set at 1300 m while, in the interests of accuracy, z1 should not be taken as less than 450 m. An attempt to measure the regression of $D_{450/1300}$ on T_{450} was made during the present study, but the available data base proved too small to allow reliable relationships to be computed. Pearce and Hamon(ref.7) have, however, provided regression curves giving partial coverage of the area under consideration. An example of the use of such relationships is given by reference 25.

4. COMPUTER PROGRAMME ORGANISATION

A computer programme has been written to compute and plot the parameters discussed in the preceding section for a series of XBT profiles. The programme is of a modular form comprising a number of separate routines which be used independently if so desired. The programme has been written to run on the IBM 370/3033 computer at DRCS and provide graphical output on a CALCOMP 12-inch plotter. ANSI standard FORTRAN IV has been used throughout, but the package calls on subroutines from two external libraries. Subroutines from the Harwell Subroutine Library have been used to fit cubic splines to data points and to perform interpolation and quadrature using the fitted curves,

----

* As pointed out by a referee, this method was originally suggested by S. Godfrey (CSIRO).

and for numerical quadrature. If this library is unavailable it is a straightforward matter to replace these subroutines with suitable equivalents. To facilitate this procedure, details of the calls to the subroutines used are contained in Appendix IX. In addition, a number of CALCOMP plotter subroutines are used, and since these may not be available for use with another installation, details of the appropriate calls are given in Appendix X. An overview of the programme appears in figure 5, and a programme listing presented in Appendix V.

For each XBT profile processed the programme produces a title block containing environmental data, followed by a listing in tabular form of the computed oceanographic parameters associated with the XBT profile. A sample output is presented in Appendix VI. In addition the programme optionally produces graphical output of two types. The first type of plot (figure 6; hereafter referred to as a 'fourplot') shows temperature/depth, salinity/depth, sound speed/depth and sigma-t/depth profiles for a specified XBT drop. In the second type of plot (figure 7; hereafter referred to as a 'longplot'), temperature/depth or sound speed/depth profiles for a sequence of XBT's are plotted.

4.1 Plotting options

The selection of the plotting options is made by means of a list-directed record input on logical unit 5. The various options are specified by four integer variables as follows:

First integer = 1 to produce fourplots,

second integer = 1 for shallow XBT (T-4) type,

= 2 for deep XBT (T-7) type,

third integer = 1 if any continuous longplots are required,

fourth integer = 1 if a temperature longplot is required,

= 2 if a sound-speed longplot is required,

= 3 if both temperature and sound-speed logplots are required.

Hence, a plot option record of 1,1,1,1 would cause a fourplot and a longplot of temperature versus depth to be plotted with the depth axis scaled for T-4 type XBT's. A blank record read on logical unit 5 will suppress plotter output. If any longplots are required, a temporary work file must be allocated to logical unit 3.

4.2 Temperature/Depth data input

The programme is written to accept data from a card image file input on logical unit 2. The following data format has been in use within Marine Sciences Composite (MSC) at DRCS since 1975. All XBT data gathered by MSC and stored on the IBM 370/3033 have been written in this format, and have been validated and calibrated. A eard image file to process a series of XBT profiles using the appended programme should be written in the following format:

RECORD 1: Contains the number of XBT profiles to follow in I10 format, left justified.

RECORD 2: A 36 character record (9A4), left justified, containing the cruise title.

RECORD 3:

Element	Starting column	Format
Day	1	A2
Month	4	A2
Year	7	A2
Time	12	A2
Longitude, °E	20	F7.2
Latitude, °S	38	F7.2

RECORD 4:

Element	Starting column	Format
Sonic Depth, M.	2	A5
Wet Temperature, °C	17	A4
Dry Temperature, °C	26	A4
Wind Direction	36	A3
Wind Speed, knots	39	A3
Barometric Pressure, mb.	49	A6

RECORD 5:

Element	Starting column	Format
Profile Number	1	I3
No. of Depth/Temperature readings (L)	4	I5

RECORDS 6 to end of profile:

Contain a sequence of L pairs of depth and temperature readings in the order D(1),T(1),D(2),T(2),...,D(L),T(L) packed in 12F6.2 format in 80 character records.

Records 2 to 6+ are repeated for each profile in the batch.

A sample input file of this type is included in Appendix VII.

The above input format is applicable only to data originating from Marine Sciences Composite; users wishing to process data from other sources must make the appropriate changes to the programme input. Details of the standard format adopted by the Australian Oceanographic Data Centre for storage of XBT data within their current data base are given in Appendix VIII. Note that the AODC format does not store certain components of the environmental data which are stored by MSC; in order to

utilise the output format used by the existing programme it is only necessary to extract cruise title and positional information together with depth and temperature figures from the input records. Note also that temperature and depth data supplied by AODC will also require correction for offset; the necessary calibration information is supplied by the parameters CALDEP and CALTEM in the input records.

REFERENCES

No.	Author	Title
1	Stommel, H.S.	"Note on the use of the T-S correlation for dynamic height anomaly computations". J. Mar. Res., Vol 5, pp 85 - 92 (1947)
2	Emery, W.J.	"Dynamic height from temperature profiles". J. Phys. Oceanogr, Vol 5, pp 369 - 375 (1975)
3	Andrews, J.C.	"The bathythermograph as a tool in gathering synoptic thermohaline data". Aust. J. Mar. Freshwater Res., Vol 27, pp 405 - 415 (1976)
4	Andrews, J.C.	"Eddy structure and the West Australian Current". Deep-Sea Res., Vol 24, pp 1133 - 1148 (1977)
5	Emery, W.J. and Wert, R.T.	"Temperature-salinity curves in the Pacific and their application to dynamic height computation". J. Phys. Oceanogr, Vol 6, pp 613 - 617 (1976)
6	Flierl, G.R.	Correcting expendable bathythermograph (XBT) data for salinity effects to compute dynamic heights in Gulf Stream rings". Deep-Sea Res., Vol 25, pp 129 - 134 (1978)
7	Pearce, A.F. and Hamon, B.V.	"Mean temperature-salinity curves for the Tasman Sea". Unpublished preliminary report, CSIRO Division of Fisheries and Oceanography (1979)
8	Hopper, M.J.	"Harwell Subroutine Library: A catalogue of subroutines (1979)". UKAEA Harwell, AERE-R9185 (1979)
9	Chen, C.-T. and Millero, F.J.	"The specific volume of seawater at high pressures". Deep-Sea Res., Vol 23, pp 595 - 612 (1976)

No.	Author	Title
10	Lighthill, M.J.	"Dynamic response of the Indian Ocean to onset of the Southwest Monsoon". Proc. Roy. Soc., Vol A265, pp 45 - 92 (1969)
11	Veronis, G.	"The properties of seawater defined by temperature, salinity, and pressure". J. Mar. Res., Vol 30, pp 227 - 255 (1972)
12	Andrews, J.C.	"Eddy structure and the West and East Australian Currents". Ph.D. Thesis, The Flinders University of South Australia (February 1979)
13	McLellan, H.J.	"Elements of Physical Oceanography". Pergamon Press (London, 1965)
14	Chen, C.-T. and Millero, F.J.	"The equation of state of seawater determined from sound speeds". J. Mar. Res., Vol 36, pp 657 - 691 (1978)
15	-	Proceedings of the Scientific Committee on Oceanic Research Vol 16, No. 1 (London, April 1980)
16	-	Ninth Report of the Joint Panel on Oceanographic Tables and Standards. UNESCO, Paris, 11 to 13 September, 1978. UNESCO Technical Papers in Marine Science, No. 30 (1979)
17	Chen, C.-T., Fine, R.A. and Millero, F.J.	"The equation of state of pure water determined from sound speeds". J. Chem. Phys., Vol 66, pp 2142 - 2144 (1977)
18	Millero, F.J., Gonzalez A. and Ward, G.K.	"The density of seawater solutions at one atmosphere as a function of temperature and salinity". J. Mar. Res., Vol 34, pp 61 - 93 (1976)
19	Neumann, G. and Pierson, W.J.	"Principles of Physical Oceanography". (Prentice-Hall, N.Y. 1966)

No.	Author	Title
20	Wang, D.P. and Millero, F.J.	"Precise representation of the P-V-T properties of water and seawater determined from sound speeds". J. Geophys. Res., Vol 78, pp 7122 - 7128 (1973)
21	Chen, C.-T. and Millero, F.J.	"Speed of sound in seawater at high pressures". J. Acoust. Soc. Am., Vol 62, pp 1129 - 1135 (1977)
22	Millero, F.J. and Leung, W.-H.	"The thermodynamics of seawater at one atmosphere". Am. J. Sci., Vol 276, pp 1035 - 1077 (1976)
23	Millero, F.J., Perron, G. and Desnoyers, J.E.	"Heat capacity of seawater solutions from 5°C to 35°C and 0.5 to 22 ppt chlorinity". J. Geophys. Res., Vol 78, pp 4499 - 4507 (1973)
24	Fofonoff, N.P.	"Physical properties of seawater". In "The Sea", Vol 1, edited by N.M. Hill, pp 3 - 30 (Interscience, N.Y., 1962)
25	Andrews, J.C., Lawrence, M. and Nilsson, C.S.	"Observations of the Tasman front". J. Phys. Oceanogr., Vol 10, pp 1854 - 1869 (1980)
26	Millero, F.J. and Poisson, A.	"International one-atmosphere equation of state of seawater". Deep-sea Res., Vol.28A, pp 625-629 (1981)

APPENDIX I NANSEN CASTS USED TO DERIVE T-S CURVES

CAST IDENT.	SOURCE	CRUISE NO.	CAST NO.	SEASON	AREA CODE	DATE	LATITUDE DEGREES	LONGITUDE DEGREES	DEPTH M.	NO. PTS.
1	RANRL	S4/3	36	WINTER	A1	19/07/68	18.00 S	152.35 E	1756	23
2	CSIRO	G1/62	11	SUMMER	A1	18/01/62	18.62 S	155.97 E	1981	18
3	CSIRO	G1/62	12	SUMMER	A1	19/01/62	18.33 S	157.72 E	3450	20
4	CSIRO	G1/62	14	SUMMER	A1	20/01/62	22.97 S	156.95 E	1983	15
5	CSIRO	G1/62	15	SUMMER	A1	20/01/62	22.90 S	158.70 E	2465	16
6	CSIRO	G1/62	24	SUMMER	A1	27/01/62	24.67 S	158.33 E	2428	16
7	CSIRO	G1/62	26	SUMMER	A1	28/02/62	24.70 S	155.37 E	1956	14
8	RANRL	S4/3	13	WINTER	A1	13/07/68	25.00 S	154.00 E	1928	24
9	RANRL	S4/3	17	WINTER	A1	14/07/68	25.12 S	157.00 E	1871	23
10	RANRL	S4/3	20	WINTER	A1	15/07/68	22.92 S	154.95 E	1977	21
11	RANRL	S4/3	25	WINTER	A1	16/07/68	20.75 S	153.50 E	1564	22
12	RANRL	S4/3	30	WINTER	A1	17/07/68	20.67 S	157.03 E	1796	23
13	CSIRO	G3/63	124	WINTER	A2	16/08/63	24.07 S	169.30 E	1500	13
14	CSIRO	G1/60	74	SUMMER	A2	22/02/60	18.17 S	167.43 E	4410	20
15	CSIRO	G1/60	66	SUMMER	A2	22/02/60	15.00 S	163.01 E	4280	20
16	CSIRO	G1/60	69	SUMMER	A2	22/02/60	17.20 S	163.62 E	3307	18
17	CSIRO	G1/60	78	SUMMER	A2	24/02/60	20.52 S	169.02 E	2421	16
18	CSIRO	G1/60	80	SUMMER	A2	25/02/60	21.98 S	167.63 E	1775	15
19	CSIRO	G2/60	112	AUTUMN	A2	24/03/60	23.32 S	165.05 E	3312	19
20	CSIRO	G2/60	114	AUTUMN	A2	24/03/60	21.53 S	163.72 E	3410	19
21	CSIRO	G2/60	119	AUTUMN	A2	25/03/60	17.92 S	161.17 E	2875	19
22	CSIRO	G2/60	121	AUTUMN	A2	26/03/60	15.93 S	160.80 E	4193	22
23	CSIRO	G1/62	20	SUMMER	A2	26/01/62	24.62 S	166.42 E	2743	17
24	CSIRO	G1/62	23	SUMMER	A2	27/01/62	24.55 S	160.37 E	1700	14
25	CSIRO	G1/60	45	SUMMER	A3	17/02/60	17.55 S	176.12 E	2500	17
26	CSIRO	G3/63	120	WINTER	A3	14/08/63	19.27 S	176.60 E	1968	15
27	CSIRO	G3/63	121	WINTER	A3	15/08/63	20.38 S	174.85 E	2320	14
28	CSIRO	G3/63	122	WINTER	A3	15/08/63	21.70 S	172.85 E	1972	14
29	CSIRO	G3/63	123	WINTER	A3	16/08/63	22.88 S	171.07 E	2000	14
30	CSIRO	G3/63	124	WINTER	A3/A2	16/08/63	24.07 S	169.30 E	1500	13
31	CSIRO	G1/60	38	SUMMER	A3	10/02/60	24.07 S	175.52 E	4273	20
32	CSIRO	G1/60	40	SUMMER	A3	11/02/60	22.75 S	175.97 E	3855	19
33	CSIRO	G1/60	41	SUMMER	A3	11/02/60	21.32 S	176.05 E	2000	15
34	CSIRO	G1/60	42	SUMMER	A3	11/02/60	20.78 S	176.33 E	2785	17
35	CSIRO	G1/60	44	SUMMER	A3	12/02/62	19.13 S	176.80 E	2977	17
36	CSIRO	G1/60	48	SUMMER	A3	17/02/60	16.68 S	174.48 E	2500	17
37	CSIRO	G1/60	50	SUMMER	A3	18/02/60	16.78 S	172.90 E	2425	17
38	CSIRO	G6/64	242	SPRING	B1	18/09/64	31.82 S	157.90 E	1500	14
39	RANRL	S4/3	6	WINTER	B1	11/07/68	29.17 S	158.03 E	1914	24
40	CSIRO	G1/62	36	SUMMER	B1	30/01/62	27.33 S	156.58 E	3365	17
41	CSIRO	G6/64	263	SPRING	B1	22/09/64	34.93 S	151.40 E	1500	14
42	CSIRO	G1/60	8	SUMMER	B1	04/02/60	33.88 S	159.88 E	1948	17
43	CSIRO	G3/64	137	AUTUMN	B1	21/03/64	34.95 S	154.25 E	1424	14
44	CSIRO	G4/63	141	SPRING	B1	11/09/63	33.03 S	155.15 E	1463	14
45	CSIRO	G2/60	91	SPRING	B1	19/03/60	30.40 S	156.53 E	4419	19
46	CSIRO	G1/64	35	SUMMER	B1	20/01/64	31.03 S	153.50 E	1500	14
47	CSIRO	G1/64	32	SUMMER	B1	20/01/64	28.58 S	154.15 E	1500	14
48	CSIRO	G1/62	23	SUMMER	B1	27/01/62	24.55 S	160.37 E	7000	14
49	RANRL	S4/3	12	WINTER	B1	12/07/68	27.17 S	154.00 E	1591	22

50	CSIRO	G1/62	42	SUMMER	B2	02/02/62	27.62	S	170.05	E	1880	13
51	CSIRO	G2/60	100	AUTUMN	B2	21/03/60	30.37	S	165.47	E	3240	18
52	CSIRO	G1/62	23	SUMMER	B2	27/01/62	24.55	S	160.37	E	1700	14
53	CSIRO	G1/62	38	SUMMER	B2	31/01/62	27.50	S	161.20	E	1600	14
54	CSIRO	G1/60	8	SUMMER	B2	04/02/60	33.88	S	159.88	E	1948	17
55	CSIRO	G1/60	13	SUMMER	B2	05/02/60	33.73	S	165.65	E	2432	17
56	CSIRO	G1/60	23	SUMMER	B2	07/02/60	33.82	S	169.10	E	1635	15
57	CSIRO	G2/60	95	AUTUMN	B2	20/03/60	30.37	S	160.78	E	1410	16
58	CSIRO	G2/60	105	AUTUMN	B2	22/03/60	28.18	S	168.38	E	3404	19
59	CSIRO	G2/60	108	AUTUMN	B2	23/03/60	26.07	S	166.63	E	3300	19
60	CSIRO	G3/63	126	WINTER	B2	17/08/63	26.20	S	165.82	E	3125	17
61	CSIRO	G3/63	127	WINTER	B2	17/08/63	27.30	S	164.08	E	2000	14
62	CSIRO	G1/62	42	SUMMER	B3	02/02/62	27.62	S	170.05	E	1880	13
63	CSIRO	G1/60	36	SUMMER	B3	10/02/60	26.35	S	175.17	E	3900	19
64	CSIRO	G1/60	25	SUMMER	B3	08/02/60	33.63	S	171.43	E	1300	13
65	CSIRO	G1/61	31	SUMMER	B3	03/02/61	34.80	S	170.38	E	2049	15
66	CSIRO	G1/60	32	SUMMER	B3	09/02/60	29.20	S	174.23	E	2842	17
67	CSIRO	G1/62	46	SUMMER	B3	03/02/62	32.07	S	173.37	E	2000	14
68	CSIRO	G1/62	44	SUMMER	B3	02/02/62	29.43	S	172.33	E	2000	14
69	CSIRO	G1/62	43	SUMMER	B3	02/02/62	27.67	S	171.95	E	3245	18
70	CSIRO	G2/60	103	AUTUMN	B3	22/03/60	30.38	S	168.73	E	3696	19
71	CSIRO	G1/60	34	SUMMER	B3	09/02/60	27.65	S	174.77	E	3400	16
72	CSIRO	G1/60	30	SUMMER	B3	09/02/60	30.73	S	173.88	E	2400	15
73	CSIRO	G1/60	28	SUMMER	B3	08/02/60	32.20	S	173.50	E	2475	16
74	CSIRO	G3/60	234	AUTUMN	C1	15/11/60	38.37	S	154.98	E	1485	14
75	CSIRO	G1/61	10	SUMMER	C1	18/01/61	43.33	S	154.73	E	1799	15
76	CSIRO	G5/63	214	SPRING	C1	13/11/63	35.33	S	151.62	E	1500	14
77	CSIRO	G3/60	167	AUTUMN	C1	05/08/64	35.45	S	155.77	E	2383	16
78	CSIRO	G1/62	52	SUMMER	C1	14/02/62	36.62	S	159.23	E	3406	17
79	CSIRO	G1/61	7	SUMMER	C1	16/01/61	44.08	S	150.88	E	2727	17
80	CSIRO	G1/61	9	SUMMER	C1	17/01/61	42.27	S	154.08	E	4019	20
81	CSIRO	G1/61	14	SUMMER	C1	20/01/61	44.60	S	158.25	E	1877	15
82	CSIRO	G1/61	15	SUMMER	C1	20/01/61	43.03	S	159.43	E	4146	20
83	CSIRO	G1/61	39	SUMMER	C1	11/01/61	37.48	S	155.53	E	1692	15
84	CSIRO	G5/63	197	SPRING	C1	10/11/63	38.50	S	151.22	E	1500	14
85	CSIRO	G1/64	74	SUMMER	C1	04/02/64	40.10	S	153.80	E	2500	16
86	CSIRO	G1/61	28	SUMMER	C2	03/02/61	35.53	S	166.83	E	1914	16
87	CSIRO	G1/61	25	SUMMER	C2	01/02/61	39.37	S	165.57	E	1782	15
88	CSIRO	G1/61	15	SUMMER	C2	20/01/61	43.03	S	159.43	E	4146	20
89	CSIRO	G1/60	8	SUMMER	C2	04/02/60	33.88	S	159.88	E	1948	17
90	CSIRO	G1/60	15	SUMMER	C2	06/02/60	35.02	S	167.23	E	2488	16
91	CSIRO	G1/60	17	SUMMER	C2	06/02/60	35.78	S	168.65	E	2275	16
92	CSIRO	G1/60	19	SUMMER	C2	07/02/60	35.88	S	170.42	E	1864	16
93	CSIRO	G1/62	51	SUMMER	C2	13/02/62	37.42	S	162.25	E	3431	18
94	CSIRO	G1/62	52	SUMMER	C2	14/02/62	36.62	S	159.23	E	3406	17
95	CSIRO	G1/61	16	SUMMER	C2	21/01/61	42.28	S	162.05	E	4443	21
96	CSIRO	G1/61	17	SUMMER	C2	22/01/61	44.85	S	162.80	E	1878	15
97	CSIRO	G1/61	26	SUMMER	C2	02/02/61	37.97	S	165.83	E	1594	15

APPENDIX II CUBIC SPLINE COEFFICIENTS FOR THE T-S CURVES

A cubic spline fitting procedure fits a piecewise cubic polynomial to a set of data points, the polynomial coefficients pertaining to adjacent segments being constrained to ensure continuity of the function and the first two derivatives at the knot points. Two entirely equivalent schemes may be used to specify the cubic spline. In the first place, the polynomial coefficients may be stated. Alternatively, the knot points together with the values of the function and its first derivative at the knot points may be specified. In keeping with the practice adopted by the Harwell Subroutine Library(ref.8), we use the latter scheme.

AREA A1

T	S	dS/dT
1.7399998	34.726685	-0.11545753
3.4487486	34.551025	-0.082896233
5.1574984	34.463531	-0.014968872
6.8662472	34.503052	0.058553696
8.5749969	34.642029	0.094157219
10.283745	34.806015	0.096733093
11.992493	34.975433	0.10424614
15.409996	35.352448	0.10685921
18.827484	35.620544	0.034598351
22.244995	35.566254	-0.057549477
25.662491	35.252518	-0.12745190
29.080002	34.667648	-0.22149563

AREA A2

T	S	dS/dT
1.7799997	34.699966	-0.084634781
5.1999969	34.441177	-0.023357391
8.6199951	34.607269	0.096752167
12.039993	34.980515	0.10944939
15.459999	35.330429	0.099792480
18.879990	35.642120	0.071731567
22.299988	35.758163	-0.011492729
25.719986	35.500107	-0.15031433
29.139999	34.654861	-0.35505390

AREA A3

T	S	dS/dT
1.8500004	34.682465	-0.090103149
3.4937487	34.517578	-0.097715378
5.1374979	34.406326	-0.022984505
6.7812462	34.443558	0.054557800
8.4249954	34.561661	0.088250160
10.068741	34.729767	0.11484337
11.712494	34.925735	0.11683750
14.999992	35.267654	0.096542358
18.287476	35.553070	0.069462776
21.574982	35.674911	-0.0027217865
24.862488	35.487518	-0.11839390
28.149994	34.840240	-0.28538132

AREA B1

T	S	dS/dT
1.1899996	34.720779	0.11289215
2.7418736	34.626480	-0.12562466
4.2937479	34.494614	-0.047614098
5.8456221	34.472565	0.018503189
7.3974972	34.548004	0.076808929
10.501244	34.888580	0.12305641
13.604996	35.243362	0.10305786
16.708740	35.510086	0.065424919
19.812500	35.633240	0.012089729
22.916245	35.589767	-0.036752701
26.020004	35.443451	-0.048524857

AREA B2

T	S	dS/dT
1.8999996	34.687988	-0.072339058
4.9149990	34.472916	-0.028326035
7.9299994	34.588760	0.086900711
10.944992	34.911652	0.11726761
13.959999	35.253723	0.10568237
16.974991	35.530823	0.076093674
19.989990	35.700470	0.034471512
23.004990	35.715652	-0.030061722
26.020004	35.457870	-0.15561867

AREA B3

T	S	dS/dT
1.8500004	34.691071	-0.13153839
7.8174982	34.583099	0.075304031
13.784996	35.247391	0.11000633
19.752487	35.713013	0.052697182
25.720001	35.447403	-0.22023773

AREA C1

T	S	dS/dT
1.1099997	34.728088	0.044359207
3.5224981	35.538361	-0.10148716
5.9349966	34.459381	0.027439117
8.3474884	34.632278	0.10853386
10.759995	34.937805	0.13336277
13.172493	35.236908	0.10989761
15.584999	35.452240	0.066784859
17.997498	35.554504	0.017894745
20.410004	35.544281	-0.023929596

AREA C2

T	S	dS/dT
1.1099997	34.742035	-0.027276993
4.0724974	34.507553	-0.065916061
7.0349951	34.523254	0.069396019
9.9974899	34.843521	0.12857723
12.959991	35.205383	0.10705471
15.922493	35.453888	0.061277390
18.884995	35.580109	0.027302742
21.847488	35.633163	0.011056900
24.809998	35.646423	-0.0043754578

APPENDIX III DENSITY PROFILES FOR THE SOUTH-WEST PACIFIC OCEAN

Area	ρ_0	$d\rho$	D	n
A1	20.5735321	7.50903416	112.234772	2.3
A2	20.4653168	7.52306175	94.4050293	1.6
A3	20.3182220	7.69532871	98.7615967	1.5
B1	23.7737579	4.32316494	220.479477	2.5
B2	23.0042877	5.02893066	168.771622	2.6
B3	23.6899109	4.32462502	194.871521	2.5
C1	25.4123688	2.72107410	417.001221	2.5
C2	25.1103363	2.98020172	328.343506	2.5

APPENDIX IV TABULATED VALUES OF SOME OCEANOGRAPHIC VARIABLES

IV.1 Salinity = 34 parts/thousand

IV.1.1 Specific volume ($cm^3.g^{-1}$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	.973429	.973822	.974496	.975419	.976563	.977912	.979452	.981172	.983064
100	.968977	.969488	.970256	.971252	.972452	.973841	.975409	.977144	.979040
200	.964662	.965283	.966139	.967204	.968457	.969884	.971478	.973228	.975129
300	.960477	.961202	.962140	.963270	.964572	.966036	.967654	.969419	.971325
400	.956417	.957239	.958254	.959444	.960793	.962292	.963934	.965712	.967623
500	.952476	.953388	.954476	.955723	.957116	.958647	.960311	.962103	.964018
600	.948651	.949646	.950801	.952101	.953535	.955097	.956782	.958586	.960506
700	.944935	.946008	.947226	.948576	.950048	.951639	.953343	.955158	.957081
800	.941325	.942470	.943746	.945142	.946651	.948267	.949990	.951816	.953742
900	.937816	.939028	.940358	.941797	.943339	.944980	.946719	.948554	.950482
1000	.934405	.935678	.937057	.938536	.940109	.941773	.943527	.945370	.947300

IV.1.2 Isothermal compressibility ($bar^{-1}.10^6$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	46.46	45.18	44.16	43.35	42.71	42.23	41.88	41.65	41.52
100	45.23	44.02	43.05	42.28	41.67	41.21	40.87	40.64	40.51
200	44.05	42.91	41.99	41.26	40.68	40.23	39.90	39.68	39.55
300	42.91	41.84	40.97	40.27	39.72	39.29	38.97	38.76	38.63
400	41.82	40.81	39.98	39.32	38.79	38.39	38.08	37.87	37.75
500	40.76	39.81	39.03	38.41	37.91	37.52	37.23	37.03	36.91
600	39.74	38.85	38.12	37.53	37.05	36.68	36.41	36.22	36.10
700	38.76	37.92	37.23	36.68	36.23	35.88	35.62	35.44	35.33
800	37.80	37.03	36.38	35.86	35.43	35.10	34.86	34.69	34.59
900	36.89	36.16	35.56	35.06	34.67	34.36	34.13	33.97	33.88
1000	36.00	35.32	34.76	34.30	33.93	33.64	33.42	33.28	33.20

IV.1.3 Thermal expansibility (degrees^{-1}.10^6)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	48.53	110.95	164.88	212.63	255.89	295.82	333.15	368.36	401.68
100	76.12	133.16	182.65	226.69	266.78	303.95	338.86	371.88	403.22
200	102.14	154.17	199.54	240.10	277.21	311.80	344.42	375.39	404.85
300	126.65	174.04	215.56	252.87	287.19	319.34	349.81	378.84	406.52
400	149.70	192.80	230.73	265.01	296.71	326.57	355.01	382.20	408.20
500	171.34	210.48	245.09	276.52	305.78	333.49	359.99	385.44	409.84
600	191.63	227.12	258.64	287.44	314.39	340.07	364.76	388.55	411.43
700	210.62	242.75	271.41	297.75	322.55	346.32	369.28	391.50	412.91
800	228.33	257.39	283.43	307.47	330.26	352.22	373.56	394.27	414.28
900	244.83	271.09	294.70	316.62	337.52	357.78	377.56	396.84	415.50
1000	260.15	283.86	305.25	325.20	344.33	362.99	381.30	399.20	416.55

IV.1.4 Specific heat, C_p (j.g^{-1}.degrees^{-1})

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	3.9926	3.9905	3.9918	3.9951	3.9991	4.0029	4.0059	4.0079	4.0090
100	3.9583	3.9606	3.9639	3.9705	3.9760	3.9809	3.9848	3.9875	3.9891
200	3.9272	3.9333	3.9361	3.9479	3.9547	3.9605	3.9651	3.9683	3.9705
300	3.8990	3.9085	3.9084	3.9271	3.9350	3.9415	3.9466	3.9504	3.9530
400	3.8735	3.8859	3.8809	3.9079	3.9167	3.9239	3.9294	3.9336	3.9366
500	3.8504	3.8654	3.8534	3.8903	3.8999	3.9075	3.9134	3.9178	3.9212
600	3.8296	3.8468	3.8260	3.8742	3.8843	3.8923	3.8984	3.9031	3.9067
700	3.8108	3.8299	3.7986	3.8594	3.8700	3.8782	3.8845	3.8893	3.8932
800	3.7939	3.8146	3.7714	3.8458	3.8567	3.8651	3.8715	3.8765	3.8806
900	3.7786	3.8008	3.7443	3.8334	3.8445	3.8530	3.8594	3.8645	3.8687
1000	3.7649	3.7883	3.7173	3.8221	3.8334	3.8418	3.8482	3.8534	3.8577

IV.1.5 Sound speed ($m.s^{-1}$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	1447.80	1447.80	1447.80	1447.80	1447.80	1447.80	1447.80	1447.80	1447.80
100	1464.19	1464.19	1464.19	1464.19	1464.19	1464.19	1464.19	1464.19	1464.19
200	1480.90	1480.90	1480.90	1480.90	1480.90	1480.90	1480.90	1480.90	1480.90
300	1497.90	1497.90	1497.90	1497.90	1497.90	1497.90	1497.90	1497.90	1497.90
400	1515.15	1515.15	1515.15	1515.15	1515.15	1515.15	1515.15	1515.15	1515.15
500	1532.62	1532.62	1532.62	1532.62	1532.62	1532.62	1532.62	1532.62	1532.62
600	1550.26	1550.26	1550.26	1550.26	1550.26	1550.26	1550.26	1550.26	1550.26
700	1568.05	1568.05	1568.05	1568.05	1568.05	1568.05	1568.05	1568.05	1568.05
800	1585.94	1585.94	1585.94	1585.94	1585.94	1585.94	1585.94	1585.94	1585.94
900	1603.90	1603.90	1603.90	1603.90	1603.90	1603.90	1603.90	1603.90	1603.90
1000	1621.90	1621.90	1621.90	1621.90	1621.90	1621.90	1621.90	1621.90	1621.90

IV.2 Salinity = 35 parts/thousand

IV.2.1 Specific volume ($cm^3.g^{-1}$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	.972664	.973070	.973755	.974685	.975835	.977189	.978733	.980456	.982350
100	.968227	.968750	.969527	.970530	.971735	.973130	.974700	.976438	.978336
200	.963926	.964558	.965423	.966494	.967751	.969183	.970779	.972532	.974435
300	.959755	.960489	.961436	.962570	.963877	.965345	.966965	.968732	.970640
400	.955707	.956538	.957560	.958755	.960108	.961610	.963254	.965035	.966947
500	.951779	.952699	.953793	.955044	.956440	.957974	.959640	.961434	.963350
600	.947965	.948968	.950128	.951433	.952869	.954434	.956120	.957925	.959846
700	.944261	.945340	.946563	.947916	.949391	.950984	.952689	.954506	.956430
800	.940661	.941812	.943093	.944492	.946002	.947620	.949344	.951170	.953097
900	.937163	.938379	.939713	.941155	.942698	.944341	.946080	.947916	.949845
1000	.933761	.935038	.936421	.937902	.939476	.941141	.942896	.944739	.946670

IV.2.2 Isothermal compressibility ($bar^{-1}.10^6$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	46.34	45.07	44.06	43.25	42.62	42.14	41.80	41.57	41.45
100	45.11	43.92	42.96	42.19	41.59	41.13	40.79	40.57	40.44
200	43.94	42.81	41.90	41.17	40.59	40.15	39.83	39.61	39.48
300	42.81	41.74	40.88	40.19	39.64	39.22	38.90	38.69	38.56
400	41.72	40.71	39.90	39.24	38.72	38.32	38.02	37.81	37.69
500	40.66	39.72	38.95	38.33	37.83	37.45	37.16	36.96	36.85
600	39.65	38.76	38.04	37.45	36.98	36.62	36.34	36.16	36.04
700	38.67	37.84	37.16	36.61	36.16	35.82	35.56	35.38	35.27
800	37.72	36.95	36.31	35.79	35.37	35.04	34.80	34.63	34.54
900	36.81	36.09	35.49	35.00	34.61	34.30	34.07	33.92	33.83
1000	35.93	35.25	34.70	34.24	33.87	33.58	33.37	33.23	33.15

IV.2.3 Thermal expansibility ($degrees^{-1}.10^6$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	51.71	113.46	166.85	214.18	257.13	296.84	334.05	369.20	402.54
100	79.05	135.47	184.47	228.12	267.92	304.89	339.69	372.68	404.04
200	104.84	156.30	201.21	241.41	278.26	312.67	345.19	376.13	405.63
300	129.12	176.00	217.09	254.07	288.15	320.14	350.52	379.53	407.27
400	151.97	194.59	232.13	266.10	297.58	327.30	355.66	382.85	408.90
500	173.42	212.12	246.36	277.52	306.57	334.15	360.60	386.05	410.51
600	193.54	228.61	259.80	288.33	315.10	340.66	365.30	389.11	412.05
700	212.36	244.11	272.47	298.56	323.19	346.85	369.78	392.01	413.50
800	229.93	258.64	284.38	308.20	330.82	352.69	373.99	394.74	414.82
900	246.30	272.22	295.56	317.27	338.02	358.19	377.95	397.26	415.99
1000	261.51	284.90	306.03	325.78	344.77	363.35	381.63	399.57	417.00

IV.2.4 Specific heat, C_p ($j.g^{-1}.degrees^{-1}$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	3.9865	3.9847	3.9864	3.9899	3.9940	3.9980	4.0011	4.0032	4.0043
100	3.9526	3.9552	3.9587	3.9655	3.9712	3.9762	3.9801	3.9828	3.9844
200	3.9219	3.9282	3.9312	3.9431	3.9500	3.9559	3.9604	3.9637	3.9658
300	3.8940	3.9036	3.9038	3.9224	3.9304	3.9370	3.9420	3.9457	3.9482
400	3.8688	3.8813	3.8765	3.9035	3.9123	3.9194	3.9249	3.9289	3.9318
500	3.8460	3.8610	3.8493	3.8860	3.8955	3.9031	3.9089	3.9132	3.9163
600	3.8254	3.8426	3.8222	3.8700	3.8801	3.8879	3.8939	3.8984	3.9019
700	3.8069	3.8260	3.7951	3.8553	3.8658	3.8738	3.8800	3.8846	3.8883
800	3.7902	3.8109	3.7682	3.8419	3.8526	3.8608	3.8670	3.8718	3.8756
900	3.7751	3.7973	3.7413	3.8296	3.8405	3.8488	3.8549	3.8598	3.8637
1000	3.7615	3.7849	3.7146	3.8184	3.8294	3.8376	3.8437	3.8486	3.8526

IV.2.5 Sound speed ($m.s^{-1}$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	1449.14	1449.14	1449.14	1449.14	1449.14	1449.14	1449.14	1449.14	1449.14
100	1465.54	1465.54	1465.54	1465.54	1465.54	1465.54	1465.54	1465.54	1465.54
200	1482.26	1482.26	1482.26	1482.26	1482.26	1482.26	1482.26	1482.26	1482.26
300	1499.27	1499.27	1499.27	1499.27	1499.27	1499.27	1499.27	1499.27	1499.27
400	1516.51	1516.51	1516.51	1516.51	1516.51	1516.51	1516.51	1516.51	1516.51
500	1533.97	1533.97	1533.97	1533.97	1533.97	1533.97	1533.97	1533.97	1533.97
600	1551.60	1551.60	1551.60	1551.60	1551.60	1551.60	1551.60	1551.60	1551.60
700	1569.37	1569.37	1569.37	1569.37	1569.37	1569.37	1569.37	1569.37	1569.37
800	1587.24	1587.24	1587.24	1587.24	1587.24	1587.24	1587.24	1587.24	1587.24
900	1605.18	1605.18	1605.18	1605.18	1605.18	1605.18	1605.18	1605.18	1605.18
1000	1623.15	1623.15	1623.15	1623.15	1623.15	1623.15	1623.15	1623.15	1623.15

IV.3 Salinity = 36 parts/thousand

IV.3.1 Specific volume ($cm^3.g^{-1}$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	.971900	.972320	.973015	.973953	.975109	.976467	.978013	.979739	.981637
100	.967478	.968014	.968800	.969810	.971021	.972418	.973991	.975732	.977634
200	.963190	.963835	.964708	.965785	.967047	.968482	.970080	.971836	.973742
300	.959033	.959779	.960732	.961872	.963183	.964654	.966276	.968046	.969956
400	.954998	.955839	.956868	.958068	.959425	.960929	.962574	.964357	.966272
500	.951082	.952011	.953111	.954367	.955766	.957302	.958969	.960764	.962684
600	.947280	.948291	.949457	.950765	.952205	.953770	.955457	.957264	.959187
700	.943587	.944674	.945901	.947258	.948735	.950328	.952035	.953852	.955779
800	.939998	.941156	.942440	.943842	.945354	.946973	.948697	.950525	.952454
900	.936509	.937732	.939069	.940513	.942059	.943702	.945441	.947278	.949209
1000	.933117	.934400	.935786	.937269	.938844	.940509	.942264	.944108	.946040

IV.3.2 Isothermal compressibility ($bar^{-1}.10^6$)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	46.22	44.96	43.96	43.16	42.54	42.06	41.72	41.49	41.37
100	45.00	43.82	42.86	42.10	41.50	41.05	40.72	40.49	40.37
200	43.83	42.71	41.81	41.08	40.51	40.08	39.75	39.54	39.41
300	42.70	41.65	40.79	40.11	39.56	39.14	38.83	38.62	38.50
400	41.61	40.62	39.81	39.16	38.65	38.25	37.95	37.74	37.62
500	40.57	39.63	38.87	38.25	37.76	37.38	37.10	36.90	36.79
600	39.56	38.68	37.96	37.38	36.91	36.55	36.28	36.10	35.99
700	38.58	37.76	37.08	36.54	36.10	35.75	35.50	35.32	35.22
800	37.64	36.87	36.24	35.72	35.31	34.98	34.74	34.58	34.48
900	36.73	36.01	35.42	34.94	34.55	34.24	34.02	33.86	33.78
1000	35.85	35.19	34.63	34.18	33.81	33.53	33.32	33.18	33.10

IV.3.3 Thermal expansibility (degrees^{-1}.10^6)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	54.89	115.96	168.80	215.71	258.35	297.85	334.94	370.06	403.43
100	81.98	137.78	186.27	229.53	269.04	305.83	340.53	373.49	404.90
200	107.54	158.43	202.86	242.70	279.29	313.53	345.97	376.90	406.45
300	131.60	177.95	218.61	255.25	289.09	320.93	351.24	380.25	408.05
400	154.24	196.38	233.52	267.18	298.44	328.02	356.32	383.52	409.64
500	175.51	213.75	247.63	278.50	307.35	334.80	361.20	386.67	411.21
600	195.45	230.11	260.95	289.22	315.80	341.25	365.85	389.69	412.71
700	214.11	245.47	273.51	299.35	323.81	347.37	370.27	392.54	414.11
800	231.54	259.88	285.32	308.91	331.38	353.16	374.44	395.22	415.39
900	247.78	273.36	296.41	317.91	338.51	358.60	378.34	397.69	416.52
1000	262.87	285.94	306.80	326.34	345.20	363.70	381.97	399.95	417.48

IV.3.4 Specific heat, C_p (j.g^{-1}.degrees^{-1})

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	3.9804	3.9790	3.9809	3.9847	3.9890	3.9931	3.9964	3.9985	3.9996
100	3.9470	3.9498	3.9536	3.9605	3.9663	3.9714	3.9754	3.9781	3.9797
200	3.9166	3.9231	3.9264	3.9383	3.9453	3.9512	3.9558	3.9590	3.9610
300	3.8891	3.8988	3.8992	3.9178	3.9258	3.9324	3.9374	3.9410	3.9435
400	3.8642	3.8768	3.8722	3.8990	3.9078	3.9149	3.9203	3.9242	3.9270
500	3.8417	3.8567	3.8453	3.8817	3.8912	3.8986	3.9043	3.9084	3.9115
600	3.8214	3.8386	3.8184	3.8658	3.8758	3.8835	3.8894	3.8937	3.8969
700	3.8030	3.8221	3.7916	3.8513	3.8616	3.8695	3.8754	3.8799	3.8833
800	3.7865	3.8072	3.7650	3.8380	3.8485	3.8565	3.8625	3.8670	3.8705
900	3.7717	3.7937	3.7384	3.8258	3.8365	3.8445	3.8504	3.8549	3.8586
1000	3.7583	3.7816	3.7119	3.8147	3.8255	3.8334	3.8392	3.8437	3.8474

IV.3.5 Sound speed (m.s-¹)

P	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	1450.48	1450.48	1450.48	1450.48	1450.48	1450.48	1450.48	1450.48	1450.48
100	1466.90	1466.90	1466.90	1466.90	1466.90	1466.90	1466.90	1466.90	1466.90
200	1483.63	1483.63	1483.63	1483.63	1483.63	1483.63	1483.63	1483.63	1483.63
300	1500.63	1500.63	1500.63	1500.63	1500.63	1500.63	1500.63	1500.63	1500.63
400	1517.87	1517.87	1517.87	1517.87	1517.87	1517.87	1517.87	1517.87	1517.87
500	1535.32	1535.32	1535.32	1535.32	1535.32	1535.32	1535.32	1535.32	1535.32
600	1552.93	1552.93	1552.93	1552.93	1552.93	1552.93	1552.93	1552.93	1552.93
700	1570.68	1570.68	1570.68	1570.68	1570.68	1570.68	1570.68	1570.68	1570.68
800	1588.53	1588.53	1588.53	1588.53	1588.53	1588.53	1588.53	1588.53	1588.53
900	1606.45	1606.45	1606.45	1606.45	1606.45	1606.45	1606.45	1606.45	1606.45
1000	1624.40	1624.40	1624.40	1624.40	1624.40	1624.40	1624.40	1624.40	1624.40

APPENDIX V LISTING OF A FORTRAN IV PROGRAMME TO PROCESS XBT DATA

V.1 Main programme

```
C XBT.PROFILE.FORT. A PROGRAMME TO CARRY OUT PRE-PROCESSING OF
C XBT DATA.
C
C THE STANDARD OUTPUT FROM THIS PROGRAMME IS A TABLE OF
C SIGNIFICANT OCEANOGRAPHIC PARAMETERS.
C PLOTTING OPTIONS ARE SELECTED FROM STANDARD INPUT DEVICE
C XBT DATA IS ASSUMED AVAILABLE FROM LOGICAL UNIT 2
C IF LNGPLT IS SELECTED A DATASET IS ASSUMED AVAILABLE ON LOGICAL UNIT 3
C FOR WRITING DATA IN PREPARATION FOR PLOTTING.
      REAL*8 K0(110),A(110),B(110),DER(110),W(330),X8(110),Y8(110)
      REAL*4 CRUISE(9),SDEP(2),BPRESS(2),SV(2),UPI(2),LAT,
     1 LONG,VP(110),TITLE1(5),TITLE2(5)
      REAL*4 Z(110),T(110),S(110),DHA(110),DELTA(110),RHO(110),KP(110),
     1  SIGMAT(110),ALPHA(110),BETA(110),V(110),P(110),G(110),V0(110),
     2  CP(110)
      DATA TITLE1/'TEMP','ERAT','URE ','- DE','G. C'/
      DATA TITLE2/'SOUN','D SP',
     1 'EED ','M/S ','    '/,SV(1),SV(2)/0.,1480./,UPI(1),UPI(2)/10.,
     2 20./
C *******
C CHOOSE PLOT OPTIONS
C*********
C
      READ(5,*) IPLT,ISCALE,ILPLT,ITYP
      WRITE(6,350) IPLT,ISCALE,ILPLT,ITYP
C
C IPLT = 1 PLOT SQUARE PLOT
C ISCALE = 1 FOR SHALLOW SQUARE PLOT
C        = 2 FOR DEEP SQUARE PLOT
C ILPLT = 1 WRITES OUTPUT TO DISC READY FOR LONG PLOT
C ITYP = 1 TEMPERATURE LONG PLOT
C      = 2 VELOCITY LONG PLOT
C      = 3 BOTH LONG PLOTS
C READ HOW MANY XBTS IN BATCH
      READ(2,10) MANY
   10 FORMAT(I10)
C LOOP ON ENTIRE PROGRAM 'MANY' TIMES
         DO 90 MM=1,MANY
         READ(2,190)(CRUISE(I),I=1,9)
         READ(2,200)DY,XMTH,YR,TIME,LONG,LAT
         READ(2,240)SDEP(1),SDEP(2),WETT,DRYT,WDIR,WSP,BPRESS(1),
     Z       BPRESS(2)
         READ(2,250)IJ,L
         IF(ILPLT .EQ.1) WRITE(3,250)IJ,L
C EVALUATE SURFACE VALUE OF GRAVITATIONAL ACCELERATION
         RLAT = 0.0174532925*LAT
         G0 = 9.78049*(1.0 + 0.0052884*(SIN(RLAT))**2 - 0.0000059*
     1       (SIN(2.0*RLAT))**2)
```

```
C Z STORED POSITIVE DOWNWARDS
C READ IN TEMPERATURE PROFILE.
        READ(2,320)(Z(I),T(I),I=1,L)
C COMPUTE SALINITY AND SIGMA-T PROFILES.
C COMMENCE LOOP ON I.
           DO 20 I=1,L
C EVALUATE LOCAL VALUE OF GRAVITATIONAL ACCELERATION.
           G(I) = G0*(1.0 + 2.26E-07*Z(I))
C COMPUTE SALINITY (PARTS/THOUSAND).
           S(I) = SAL(LAT,LONG,T(I))
           CALL DSW1(S(I),T(I),V0(I),RHO(I),SIGMAT(I))
           CALL DSW1A(S(I),T(I),K0(I),A(I),B(I))
C AS AN INITIAL APPROXIMATION, SET SPECIFIC VOLUME UNDER PRESSURE EQUAL
C TO VALUE AT ATMOSPHERIC PRESSURE.
           VP(I) = V0(I)
C CONVERT Z AND RHO TO DOUBLE PRECISION
           Y8(I) = DBLE(Z(I))
           X8(I) = DBLE(RHO(I))
C END OF LOOP ON I.
   20      CONTINUE
C COMMENCE ITERATION TO CORRECT FOR PRESSURE BY FITTING CUBIC SPLINE
C TO CURRENT DENSITY ESTIMATES.
        P(1) = 0.0
   30   CONTINUE
        CALL TB04AD(L,Y8,X8,DER,W)
        IF (W(1).EQ.1.0) WRITE(6,40)
   40 FORMAT(' UNSUCCESSFUL RETURN FROM TB04A.')
        DV = 0.0
           DO 50 J=2,L
C LOOP ON DATA POINTS TO COMPUTE PRESSURES AND SUBSEQUENTLY DENSITY
C CORRECTIONS (INDEX J).
           P(J) = 1.0E-02*G(J)*QG02AD(0.0,Y8(J),L,Y8,X8,DER)
           CALL DSW2(P(J),V0(J),K0(J),A(J),B(J),KP(J),VN,BETA(J))
           IF ( ABS(VN-VP(J)).GT.DV) DV =  ABS(VN - VP(J))
           VP(J) = VN
           RHO(J) = 1.0/VP(J)
           X8(I) = DBLE(RHO(J))
C END OF LOOP ON J.
   50      CONTINUE
C CHECK WHETHER FURTHER ITERATIONS ARE REQUIRED.
                                                IF (DV.GT.1.0E-08) GO TO 30
C EVALUATE SPECIFIC VOLUME ANOMALY.
C SAL AT 35PPT TEMP AT 0DEG
        CALL DSW1(35.,0.,V0F,RHOF,STF)
        CALL DSW1A(35.,0.,K0F,AF,BF)
           DO 60 I=1,L
           CALL DSW2(P(I),V0F,K0F,AF,BF,KPF,V2,BETAF)
C COMPUTE SPECIFIC VOLUME ANOMALY.
C END OF LOOP ON I.
           DELTA(I) =VP(I)- V2
C COMPUTE SOUND SPEED FROM TEMP,SAL, AND PRESSURE.
           CALL SSSW1(P(I),S(I),T(I),V(I))
C COMPUTE EXPANSIBILITY AND SPECIFIC HEAT.
           CALL PSW1(S(I),T(I),P(I),V0(I),VP(I),K0(I),A(I),B(I),ALPHA(I
     1     ),     CP(I))
C CONVERT P AND DELTA TO DOUBLE PRECISION
           Y8(I) = DBLE(P(I))
```

```
           X8(I) = DBLE(DELTA(I))
  60       CONTINUE
C FIT A CUBIC SPLINE TO SPECIFIC VOLUME ANOMALY VS. PRESSURE.
        CALL TB04AD(L,Y8,X8,DER,W)
        IF (W(1).EQ.1.0) WRITE(6,40)
C EVALUATE DYNAMIC HEIGHT ANOMALY, REFERRED TO THE SURFACE.
           DO 70 I=1,L
  70       DHA(I) = 10.*QG02AD(0.0,Y8(I),L,Y8,X8,DER)
C OUTPUT PROFILE.
        WRITE(6,220)(CRUISE(I),I=1,9)
        WRITE(6,160) IJ
        WRITE(6,170)
        WRITE(6,180)
        WRITE(6,210) DY,XMTH,YR,TIME,LONG,LAT
        WRITE(6,170)
        WRITE(6,230)
        WRITE(6,260)SDEP(1),SDEP(2),WETT,DRYT,WDIR,WSP,BPRESS(1),
     Z       BPRESS(2)
        WRITE(6,170)
        WRITE(6,270)
        WRITE(6,280)
        WRITE(6,290)
        WRITE(6,300)
        WRITE(6,310)
        WRITE(6,270)
        WRITE(6,170)
           DO 80 I=1,L
           ALPHA(I) = ALPHA(I) * 1E06
           BETA(I)  = BETA(I)  * 1E06
           WRITE(6,330) Z(I),T(I),S(I),DHA(I),DELTA(I),RHO(I),
     Z            SIGMAT(I),ALPHA(I),BETA(I),V(I),P(I),CP(I)
           IF(ILPLT.EQ.1)
     Y           WRITE(3,340) Z(I),T(I),S(I),DHA(I),DELTA(I),RHO(I),
     Z                 SIGMAT(I),ALPHA(I),BETA(I),V(I),P(I),CP(I)
  80       CONTINUE
        WRITE(6,170)
        IF(IPLT.EQ.1) CALL PLOT1(Z,T,S,SIGMAT,V,L,IJ,ISCALE)
  90    CONTINUE
                                              IF(ILPLT.NE.1) GO TO 150
     IF(ITYP.EQ.3) NPLT = 2
     IF(ITYP.NE.3) NPLT = 1
        DO 140 IN=1,NPLT
        REWIND 3
           DO 130 IK=1,MANY
           READ(3,250) IJ,L
              DO 100 I=1,L
              READ(3,360) Z(I),T(I),V(I)
 100          CONTINUE
                                              IF(ITYP.EQ.1) GO TO 110
                                              IF(ITYP.EQ.2) GO TO 120
                                     IF(ITYP.EQ.3.AND.IN.EQ.1) GO TO 110
                                     IF(ITYP.EQ.3.AND.IN.EQ.2) GO TO 120
 110       IF(IK.EQ.1) CALL LNGPLT(SV(1),UPI(1),TITLE1,T,Z,L,
     1           IJ,IK,MANY)
           IF(IK.NE.1) CALL ADDPLT(T,Z,L,IJ,IK)
                                                          GO TO 130
 120       IF(IK.EQ.1) CALL LNGPLT(SV(2),UPI(2),TITLE2,V,Z,L,
```

```
     1              IJ,IK,MANY)
            IF(IK.NE.1) CALL ADDPLT(V,Z,L,IJ,IK)
  130       CONTINUE
  140    CONTINUE
      CALL ENDGR
  150 STOP
  160 FORMAT(47X,'XBT NUMBER',I3)
  170 FORMAT(1H0)
  180 FORMAT(32X,'DATE',7X,'TIME',6X,'LONGTITUDE',8X,'LATITUDE')
  190 FORMAT(9A4)
  200 FORMAT(A2,1X,A2,1X,A2,3X,A4,4X,F7.2,11X,F6.2)
  210 FORMAT(30X,2(A2,'/'),A2,5X,A4,5X,F6.2,' DEG.E',6X,F5.2,' DEG.S')
  220 FORMAT(1H1,37X,9A4)
  230 FORMAT(17X,'SONIC DEPTH',7X,'AIR TEMPERATURE(DEG.C)',11X,'WIND',
     Z12X,'ATMOS.PRESS')
  240 FORMAT(1X,A3,A2,10X,A4,5X,A4,6X,A3,A3,9X,A4,A2)
  250 FORMAT(I3,I5)
  260 FORMAT(19X,A3,A2,'M',10X,'WET ',A4,5X,'DRY ',A4,5X,'DIR ',
     ZA3,3X,A3,' KNOTS',5X,A4,A2,' MB')
  270 FORMAT('--------------------------------------------------------
     ----------------------------------------------------------')
  280 FORMAT(' DEPTH  TEMPERATURE SALINITY DYNAMIC HT.   DELTA   DENSITY
     Z    SIGMA-T     ALPHA     BETA      SOUND     PRESSURE  SPECIFIC')
  290 FORMAT(31X,'ANOMALY',53X'SPEED',16X,'HEAT')
  300 FORMAT(2X,'M',9X,'C',8X,'PPT',7X,'DYNM',6X'CM**3/GM',2X
     Z,'GM/CM**3',' (GM/CM**3)',2X,'*10**6/',2X,'*10**6/',3X,'M/SEC',6X,
     Y ' BAR')
  310 FORMAT(62X,'/1000',6X,'DEG.C',5X,'BAR',24X,'J/G/DEG')
  320 FORMAT(12F6.2)
  330 FORMAT(1X,F6.0,4X,F5.2,5X,F5.2,5X,F6.3,4X,F8.6,2X,F8.6,2X,F7.3,
     Z5X,F5.1,4X,F5.2,3X,F7.2,4X,F6.3,4X,F6.4)
  340 FORMAT(F6.0,F5.2,F5.2,F6.3,F8.6,F8.6,F7.3,
     ZF5.1,F5.2,F7.2,F7.1,F6.4)
  350 FORMAT(' IPLT = ', I2,' ISCALE = ',I2,' ILPLT = ', I2, 'ITYP = ',
     Z  I2)
  360 FORMAT(F6.0,F5.2,44X,F7.2)
      END
```

V.2 Subroutine DSW1

```
      SUBROUTINE DSW1(S,T,VO,RO,SIGMAT)
C A SUBROUTINE TO DETERMINE THE SPECIFIC VOLUME OF SEAWATER AT
C ATMOSPHERIC PRESSURE AND SPECIFIED SALINITY AND TEMPERATURE USING THE
C SOUND-SPEED DERIVED EQUATION OF STATE OF CHEN AND MILLERO (1).
C INPUT PARAMETERS:
C S      REAL*4. SALINITY (PARTS/THOUSAND).
C T      REAL*4. TEMPERATURE (DEGREES CENTIGRADE).
C OUTPUT PARAMETERS:
C VO     REAL*4. SPECIFIC VOLUME OF SEAWATER (CM**3/G) AT ATMOSPHERIC
C        PRESSURE AND SPECIFIED SALINITY AND TEMPERATURE.
C RO     REAL*4. CORRESPONDING DENSITY (G/CM**3).
C SIGMAT REAL*4. CORRESPONDING VALUE OF SIGMA-T ((G/CM**3)*10**-3).
C REFERENCE:
```

```
C (1) CHEN, C.-T., AND MILLERO, F.J. 1978. THE EQUATION OF STATE OF
C     SEAWATER DETERMINED FROM SOUND SPEEDS. J. MAR. RES., VOL. 36,
C     657-691.
C
      REAL*8 A0,A1,A2,A3,A4,A5,A6
      REAL*8 B0,B1,B2,B3,B4
      REAL*8 C0,C1,C2,C3
      REAL*8 D0,D1,D2,D3
      REAL*8 AT,BT,CT,DT
      DATA A0,A1,A2,A3,A4,A5,A6/0.9998395,6.7914D-05,-9.0894D-06,
     1 1.0171D-07,-1.2846D-09,1.1592D-11,-5.0125D-14/
      DATA B0,B1,B2,B3,B4/8.25917D-04,-4.4490D-06,1.0485D-07,
     1 -1.2580D-09,3.315D-12/
      DATA C0,C1,C2,C3/-6.33761D-06,2.8441D-07,-1.6871D-08,2.83258D-10/
      DATA D0,D1,D2,D3/5.4705D-07,-1.97975D-08,1.6641D-09,-3.1203D-11/
C DETERMINE THE DENSITY OF SEAWATER AT ATMOSPHERIC PRESSURE.
      AT = A0 + T*(A1 + T*(A2 + T*(A3 + T*(A4 + T*(A5 + T*A6)))))
      BT = B0 + T*(B1 + T*(B2 + T*(B3 + T*B4)))
      CT = C0 + T*(C1 + T*(C2 + T*C3))
      DT = D0 + T*(D1 + T*(D2 + T*D3))
      R0 = AT + S*(BT + CT*SQRT(S) + DT*S)
C DETERMINE THE CORRESPONDING VALUES OF SIGMA-T AND SPECIFIC VOLUME.
      SIGMAT = 1000.0*(R0 - 1.0)
      V0 = 1.0/R0
      RETURN
      END
```

V.3 *Subroutine DSW1A*

```
      SUBROUTINE DSW1A(S,T,K0,A,B)
C A SUBROUTINE TO DETERMINE THE PRESSURE CORRECTION COEFFICIENTS FOR THE
C SPECIFIC VOLUME OF SEAWATER AT SPECIFIED SALINITY AND TEMPERATURE
C USING THE SOUND-SPEED DERIVED EQUATION OF STATE OF CHEN AND MILLERO
C (1).
C INPUT PARAMETERS:
C S       REAL*4. SALINITY (PARTS/THOUSAND).
C T       REAL*4. TEMPERATURE (DEGREES CENTIGRADE).
C OUTPUT PARAMETERS:
C K0,A,B REAL*8. PRESSURE CORRECTION COEFFICIENTS (SEE REFERENCE 1).
C REFERENCES:
C (1) CHEN, C.-T., AND MILLERO, F.J. 1978. THE EQUATION OF STATE OF
C     SEAWATER DETERMINED FROM SOUND SPEEDS. J. MAR. RES., VOL. 36,
C     657-691.
C
      REAL*8 KW0,KW1,KW2,KW3,KW4,KW5
      REAL*8 AW0,AW1,AW2,AW3,AW4
      REAL*8 BW0,BW1,BW2,BW3,BW4
      REAL*8 AS0,AS1,AS2,AS3
      REAL*8 BS0,BS1
      REAL*8 CS0,CS1,CS2
      REAL*8 DS
      REAL*8 ES0,ES1,ES2
      REAL*8 K0,A,B,KW,AW,BW,AS,BS,CS,ES
```

```
      DATA KW0,KW1,KW2,KW3,KW4,KW5/19652.17,148.183,-2.29995,1.281D-02,
     1 -4.91564D-05,1.03553D-07/
      DATA AW0,AW1,AW2,AW3,AW4/3.26138,5.223D-04,1.324D-04,-7.655D-07,
     1 8.584D-10/
      DATA BW0,BW1,BW2,BW3,BW4/7.2061D-05,-5.8948D-06,8.699D-08,
     1 -1.010D-09,4.322D-12/
      DATA AS0,AS1,AS2,AS3/53.751,-0.4607,7.030D-03,-5.107D-05/
      DATA BS0,BS1/0.2322,-4.838D-03/
      DATA CS0,CS1,CS2/4.692D-03,-8.387D-05,4.68D-07/
      DATA DS/-1.332D-04/
      DATA ES0,ES1,ES2/-1.412D-06,9.006D-08,-1.551D-09/
C EVALUATE THE PRESSURE CORRECTION COEFFICIENTS.
      AS = AS0 + T*(AS1 + T*(AS2 + T*AS3))
      BS = BS0 + T*BS1
      CS = CS0 + T*(CS1 + T*CS2)
      ES = ES0 + T*(ES1 + T*ES2)
      KW = KW0 + T*(KW1 + T*(KW2 + T*(KW3 + T*(KW4 + T*KW5))))
      AW = AW0 + T*(AW1 + T*(AW2 + T*(AW3 + T*AW4)))
      BW = BW0 + T*(BW1 + T*(BW2 + T*(BW3 + T*BW4)))
      S32 = S*SQRT(S)
      K0 = KW + AS*S + BS*S32
      A = AW + CS*S + DS*S32
      B = BW + ES*S
      RETURN
      END
```

V.4 Subroutine DSW2

```
      SUBROUTINE DSW2(P,V0,K0,A,B,KP,VP,BETA)
C A SUBROUTINE TO DETERMINE THE SPECIFIC VOLUME AND ISOTHERMAL
C COMPRESSIBILITY OF SEAWATER AT A SPECIFIED PRESSURE, TEMPERATURE AND
C SALINITY. IT IS ASSUMED THAT PREVIOUS CALLS TO DSW1 AND DSW1A HAVE
C BEEN MADE,AND THAT THE SPECIFIC VOLUME AT ONE ATMOSPHERE PRESSURE,
C AND THE PRESSURE CORRECTION COEFFICIENTS HAVE BEEN COMPUTED.
C INPUT PARAMETERS:
C P     REAL*4. PRESSURE (BARS).
C V0    REAL*4. SPECIFIC VOLUME OF SEAWATER (CM**3/G) AT ONE ATMOSPHERE
C       PRESSURE.
C K0,A,B REAL*8. PRESSURE CORRECTION COEFFICIENTS (SEE REFERENCE 1).
C OUTPUT PARAMETERS:
C KP    REAL*4. SECANT BULK MODULUS (BARS) AT SPECIFIED TEMPERATURE,
C       PRESSURE AND SALINITY.
C VP    REAL*4. SPECIFIC VOLUME OF SEAWATER (CM**3/G) CORRECTED FOR THE
C       EFFECT OF PRESSURE.
C BETA REAL*4. ISOTHERMAL COMPRESSIBILITY OF SEAWATER (BAR**-1).
C REFERENCE:
C (1) CHEN, C.-T., AND MILLERO, F.J. 1978. THE EQUATION OF STATE OF
C     SEAWATER DETERMINED FROM SOUND SPEEDS. J. MAR. RES., VOL. 36,
C     657-691.
C
      REAL*4 KP
      REAL*8 K0,A,B
C COMPUTE THE SECANT BULK MODULUS.
```

```
      KP = K0 + P*(A + P*B)
C COMPUTE THE SPECIFIC VOLUME OF SEAWATER AT ELEVATED PRESSURE.
      VP = V0*(1.0 - P/KP)
C COMPUTE THE ISOTHERMAL COMPRESSIBILITY OF SEAWATER.
      BETA = V0*(K0 - B*P*P)/(VP*KP*KP)
      RETURN
      END
```

V.5 Subroutine PSW1

```
      SUBROUTINE PSW1(S,T,P,V0,VP,K0,A,B,ALPHA,CP)
C A SUBROUTINE TO COMPUTE THE EXPANSIBILITY AND CONSTANT-PRESSURE
C SPECIFIC HEAT OF SEAWATER AT SPECIFIED TEMPERATURE, PRESSURE AND
C SALINITY. IT IS ASSUMED THAT PRIOR CALLS HAVE BEEN MADE TO SUBROUTINES
C DSW1, DSW1A AND DSW2 TO COMPUTE THE SPECIFIC VOLUME OF SEAWATER AT
C ATMOSPHERIC PRESSURE AND AT PRESSURE P, AND THE PRESSURE CORRECTION
C COEFFICIENTS K0, A AND B.
C INPUT PARAMETERS:
C S       REAL*4. SALINITY (PARTS/THOUSAND).
C T       REAL*4. TEMPERATURE (DEGREES CENTIGRADE).
C P       REAL*4. PRESSURE (BARS).
C V0      REAL*4. SPECIFIC VOLUME OF SEAWATER (CM**3/G) AT SPECIFIED
C         SALINITY AND TEMPERATURE AND ATMOSPHERIC PRESSURE.
C VP      REAL*4. SPECIFIC VOLUME OF SEAWATER (CM**3/G) AT SPECIFIED
C         TEMPERATURE, PRESSURE AND SALINITY.
C K0,A,B  REAL*8. PRESSURE CORRECTION COEFFICIENTS (SEE REFERENCE 1).
C OUTPUT PARAMETERS:
C ALPHA   REAL*4. EXPANSIBILITY OF SEAWATER (DEGREES CENTIGRADE**-1) AT
C         SPECIFIED SALINITY, TEMPERATURE AND PRESSURE.
C CP      REAL*4. CONSTANT PRESSURE SPECIFIC HEAT OF SEAWATER
C         (J.G**-1.DEG**-1) AT SPECIFIED SALINITY, TEMPERATURE AND
C         PRESSURE.
C REFERENCE:
C (1) CHEN, C.-T., AND MILLERO, F.J. 1978. THE EQUATION OF STATE OF
C     SEAWATER DETERMINED FROM SOUND SPEEDS. J. MAR. RES., VOL. 36,
C     657-691.
C
      REAL*8 DRDT,DVDT,DKDT,DADT,DBDT,X,D2RDT2,D2VDT2,D2KDT2,D2ADT2,
     1 D2BDT2,CPW0,ACP,BCP,CP0,Q,I10,I11,I20,I21,I22,I23,I30,I31,I32,
     2 I33,I34,I35,A1,B1,B2,B3,C1,C2,C3,C4,C5,I2,DSQ,ABP2,KB2AS,K0,A,B,
     3 TBPA,DSQ,QX,QK0,XSQ,K0SQ,K0D,AD,BD,PD,AERR,RERR,ERROR
      REAL*8 DDER
      COMMON/PSW1A/K0D,AD,BD,DVDT,D2VDT2,DKDT,D2KDT2,DADT,D2ADT2,
     1 DBDT,D2BDT2
      EXTERNAL DDER
      K0D = K0
      AD = A
      BD = B
      PD = P
      AERR = 1.0D-06
      RERR = 1.0D-06
C EVALUATE FIRST-ORDER PARTIAL DERIVATIVES.
      DRDT = 6.7914D-05 + T*(-1.81788D-05 + T*(3.0513D-07 +
```

```
     1 T*(-5.1384D-09 + T*(5.796D-11 - T*3.0075D-13)))) +
     2 S*(-4.4490D-06 + T*(2.097D-07 + T*(-3.774D-09 + T*1.326D-11)) +
     3 SQRT(S)*(2.8441D-07 + T*(-3.3742D-08 + T*8.49774D-10)) +
     4 S*(-1.97975D-08 + T*(3.3282D-09 - T*9.3609D-11)))
      DVDT = -V0*V0*DRDT
      DKDT = 1.48183D+02 + T*(-4.5999D+00 + T*(3.843D-02 +
     1 T*(-1.966256D-04 + T*5.17765D-07))) + S*(-4.607D-01 +
     2 T*(1.406D-02 - T*1.5321D-04) - 4.838D-03*SQRT(S))
      DADT = 5.223D-04 + T*(2.648D-04 + T*(-2.2965D-06 + T*3.4336D-09))
     1 + S*(-8.387D-05 + T*9.36D-07)
      DBDT = -5.8948D-06 + T*(1.7398D-07 + T*(-3.03D-09 +
     1 T*1.7288D-11)) + S*(9.006D-08 - T*3.102D-09)
C COMPUTE EXPANSIBILITY.
      X = K0 + P*(A + P*B)
      ALPHA = DVDT/VP - P*DVDT/(VP*X) + P*V0*(DKDT + P*(DADT +
     1 P*DBDT))/(VP*X*X)
C EVALUATE SECOND-ORDER PARTIAL DERIVATIVES.
      D2RDT2 = -1.81788D-05 + T*(6.1026D-07 + T*(-1.54152D-08 +
     1 T*(2.3184D-10 - T*1.50375D-12))) + S*(2.097D-07 + T*(-7.548D-09 +
     2 T*3.978D-11) + SQRT(S)*(-3.3742D-08 + T*1.699548D-09) +
     3 S*(3.3282D-09 - T*1.87218D-10))
      D2VDT2 = V0*V0*(-D2RDT2 + 2.0*V0*DRDT*DRDT)
      D2KDT2 = -4.5999 + T*(7.686D-02 + T*(-5.898768D-04 +
     1 T*2.07106D-06)) + S*(1.406D-02 - T*3.0642D-04)
      D2ADT2 = 2.648D-04 + T*(-4.593D-06 + T*1.03008D-08) + S*9.36D-07
      D2BDT2 = 1.7398D-07 + T*(-6.06D-09 + T*5.1864D-11) - S*3.102D-09
C COMPUTE SPECIFIC HEAT OF SEAWATER AT ATMOSPHERIC PRESSURE.
      CPW0 = 4.2174D+00 + T*(-3.720283D-03 + T*(1.412855D-04 +
     1 T*(-2.654387D-06 + T*2.093236D-08)))
      ACP = -7.644D-03 + T*(1.0727D-04 - T*1.38D-06)
      BCP = 1.77D-04 + T*(-4.08D-06 + T*5.35D-08)
      CP0 = CPW0 + S*(ACP + SQRT(S)*BCP)
C EVALUATE INTEGRAL IN THE SPECIFIC HEAT EQUATION. IF |B|<0.5D-05,
C INTEGRATE NUMERICALLY, OTHERWISE USE ANALYTICAL EXPRESSION.
      IF (DABS(B).LT.0.5D-05) GO TO 1
      Q = 4.0*K0*B - A*A
      TBPA = 2.0*B*P + A
      IF (Q.GT.0.0D+00) DSQ = DSQRT(Q)
      IF (Q.LT.0.0D+00) DSQ = DSQRT(-Q)
      QX = Q*X
      QK0 = Q*K0
      XSQ = X*X
      K0SQ = K0*K0
      IF (Q.GT.0.0D+00) I10 = 2.0*(DATAN(TBPA/DSQ) - DATAN(A/DSQ))/DSQ
      IF (Q.LT.0.0D+00) I10 = DLOG((TBPA - DSQ)*(A + DSQ)/((TBPA + DSQ)
     1 *(A - DSQ)))/DSQ
      I20 = TBPA/QX - A/QK0 + 2.0*B*I10/Q
      I11 = 0.5*DLOG(X/K0)/B - 0.5*A*I10/B
      I21 = -0.5*(1.0/X - 1.0/K0)/B - 0.5*A*I20/B
      I22 = (-P/X + K0*I20)/B
      I23 = (I11 - K0*I21 - A*I22)/B
      I30 = (0.5*(TBPA/XSQ - A/K0SQ) + 3.0*B*I20)/Q
      I31 = (-0.25*(1.0/XSQ - 1.0/K0SQ) - 0.5*A*I30)/B
      I32 = (-P/XSQ - A*I31 + K0*I30)/(3.0*B)
      I33 = (-0.5*P*P/XSQ + K0*I31)/B
      I34 = (-P**3/XSQ + A*I33 + 3.0*K0*I32)/B
      I35 = (I23 - K0*I33 - A*I34)/B
```

```
C EVALUATE COEFFICIENTS.
      A1 = -D2VDT2
      B1 = 2.0*DVDT*DKDT + V0*D2KDT2
      B2 = 2.0*DVDT*DADT + V0*D2ADT2
      B3 = 2.0*DVDT*DBDT + V0*D2BDT2
      C1 = -2.0*V0*DKDT*DKDT
      C2 = -4.0*V0*DADT*DKDT
      C3 = -4.0*V0*DBDT*DKDT - 2.0*V0*DADT*DADT
      C4 = -4.0*V0*DADT*DBDT
      C5 = -2.0*V0*DBDT*DBDT
C COMPUTE SPECIFIC HEAT.
      I2 = P*D2VDT2 + A1*I11 + B1*I21 + B2*I22 + B3*I23 + C1*I31 +
     1 C2*I32 + C3*I33 + C4*I34 + C5*I35
      GO TO 2
    1 CALL QA05AD(I2,DDER,0.0D+00,PD,AERR,RERR,1,ERROR,IFLAG)
      IF (IFLAG.GT.3) WRITE(6,601) IFLAG
  601 FORMAT(' POSSIBLE ERROR IN INTEGRAL EVALUATION, IFLAG = ',I2)
    2 CP = CP0 - 0.1*(T + 273.15)*I2
      RETURN
      END
```

V.6 Function DDER

```
      DOUBLE PRECISION FUNCTION DDER(P)
C A FUNCTION TO EVALUATE THE SECOND DERIVATIVE OF SPECIFIC VOLUME
C WITH RESPECT TO TEMPERATURE AT A SPECIFIED PRESSURE, P.
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/PSW1A/K0,A,B,DVDT,D2VDT2,DKDT,D2KDT2,DADT,D2ADT2,
     1 DBDT,D2BDT2
      REAL*8 K0
      X = K0 + P*(A + P*B)
      DS1 = DKDT + P*(DADT + P*DBDT)
      DS2 = D2KDT2 + P*(D2ADT2 + P*D2BDT2)
      DDER = D2VDT2 + (-P*D2VDT2 + P*((2.0*DVDT*DS1 + V0*DS2) -
     1 2.0*V0*DS1*DS1/X)/X)/X
      RETURN
      END
```

V.7 Subroutine SSSW1

```
      SUBROUTINE SSSW1(P,S,T,U)
C A SUBROUTINE TO COMPUTE THE SPEED OF SOUND IN SEAWATER AT SPECIFIED
C PRESSURE, SALINITY AND TEMPERATURE. THE RELATIONSHIP OF CHEN AND
C MILLERO (1) IS USED.
C INPUT PARAMETERS:
C P REAL*4. PRESSURE (BARS).
C S REAL*4. SALINITY (PARTS/THOUSAND).
C T REAL*4. TEMPERATURE (DEGREES CENTIGRADE).
C OUTPUT PARAMETER:
C U REAL*4. SPEED OF SOUND (M/SEC) AT SPECIFIED PRESSURE, SALINITY AND
```

```
C          TEMPERATURE.
C REFERENCE:
C (1) CHEN, C.-T., AND MILLERO, F.J. 1977. SPEED OF SOUND IN SEAWATER
C     AT HIGH PRESSURES. J. ACOUST. SOC. AM., VOL. 62, PP. 1129-1135.
C
      REAL*8 AH0,AH1,AH2,AH3,AH4,AH5
      REAL*8 BH0,BH1,BH2,BH3,BH4
      REAL*8 CH0,CH1,CH2,CH3,CH4
      REAL*8 DH0,DH1,DH2
      REAL*8 AD0,AD1,AD2,AD3,AD4
      REAL*8 BD0,BD1
      REAL*8 A10,A11,A12,A13,A14
      REAL*8 A20,A21,A22,A23
      REAL*8 A30,A31,A32
      REAL*8 B0,B1
      REAL*8 C0
      REAL*8 AH,BH,CH,DH,AD,BD,CD,A1,A2,A3,A,B,C,UPH2O,UD
      DATA AH0,AH1,AH2,AH3,AH4,AH5/1402.388,5.03711,-5.80852D-02,
     1 3.3420D-04,-1.47800D-06,3.1464D-09/
      DATA BH0,BH1,BH2,BH3,BH4/0.153563,6.8982D-04,-8.1788D-06,
     1 1.3621D-07,-6.1185D-10/
      DATA CH0,CH1,CH2,CH3,CH4/3.1260D-05,-1.7107D-06,2.5974D-08,
     1 -2.5335D-10,1.0405D-12/
      DATA DH0,DH1,DH2/-9.7729D-09,3.8504D-10,-2.3643D-12/
      DATA AD0,AD1,AD2,AD3,AD4/1.389,-1.262D-03,7.164D-05,2.006D-06,
     1 -3.21D-08/
      DATA BD0,BD1/-1.922D-02,-4.42D-05/
      DATA CD/1.727D-03/
      DATA A10,A11,A12,A13,A14/9.4742D-05,-1.2580D-05,-6.4885D-08,
     1 1.0507D-08,-2.0122D-10/
      DATA A20,A21,A22,A23/-3.9064D-07,9.1041D-09,-1.6002D-10,7.988D-12/
      DATA A30,A31,A32/1.100D-10,6.649D-12,-3.389D-13/
      DATA B0,B1/7.3637D-05,1.7945D-07/
      DATA C0/-7.9836D-06/
C COMPUTE THE SPEED OF SOUND IN PURE WATER AT THE DESIGNATED TEMPERATURE
C AND PRESSURE.
      AH = AH0 + T*(AH1 + T*(AH2 + T*(AH3 + T*(AH4 + T*AH5))))
      BH = BH0 + T*(BH1 + T*(BH2 + T*(BH3 + T*BH4)))
      CH = CH0 + T*(CH1 + T*(CH2 + T*(CH3 + T*CH4)))
      DH = DH0 + T*(DH1 + T*DH2)
      UPH2O = AH + P*(BH + P*(CH + P*DH))
C COMPUTE THE DIFFERENTIAL BETWEEN THE SPEED OF SOUND IN SEAWATER AND
C IN PURE WATER AT THE DESIGNATED TEMPERATURE AND PRESSURE.
      AD = AD0 + T*(AD1 + T*(AD2 + T*(AD3 + T*AD4)))
      BD = BD0 + T*BD1
      UD = S*(AD + BD*SQRT(S) + CD*S)
C COMPUTE THE SPEED OF SOUND IN SEAWATER AT DESIGNATED TEMPERATURE,
C PRESSURE AND SALINITY.
      A1 = A10 + T*(A11 + T*(A12 + T*(A13 + T*A14)))
      A2 = A20 + T*(A21 + T*(A22 + T*A23))
      A3 = A30 + T*(A31 + T*A32)
      A = P*(A1 + P*(A2 + P*A3))
      B = P*(B0 + T*B1)
      C = C0*P
      U = S*(A + B*SQRT(S) + C*S) + UD + UPH2O
      RETURN
      END
```

V.8 Function SAL

```
      FUNCTION SAL(LAT4,LONG4,T4)
C A FUNCTION TO COMPUTE THE SALINITY CORRESPONDING TO A GIVEN
C TEMPERATURE IN A SPECIFIC GEOGRAPHICAL LOCATION USING A STANDARD T-S
C CURVE.
C PARAMETERS PASSED:
C LAT4   REAL*4. LATITUDE (DEGREES).
C LONG4  REAL*4. LONGITUDE (DEGREES).
C T4     REAL*4. TEMPERATURE (DEGREES CENTIGRADE).
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 LAT4,LONG4,T4
      REAL*8 XN(8,12),FN(8,12),GN(8,12),X(12),F(12),G(12),LAT,LONG
      INTEGER*4 NP(8)
      DATA NP(1),NP(2),NP(3),NP(4),NP(5),NP(6),NP(7),NP(8)/
     1 12,9,12,11,9,5,9,9/
      DATA XN(1,1),XN(1,2),XN(1,3),XN(1,4),XN(1,5),XN(1,6),XN(1,7),
     1 XN(1,8),XN(1,9),XN(1,10),XN(1,11),XN(1,12)/1.7399998,3.4487486,
     2 5.1574984,6.8662472,8.5749969,10.283745,11.992493,15.409996,
     3 18.827484,22.244995,25.662491,29.080002/
      DATA FN(1,1),FN(1,2),FN(1,3),FN(1,4),FN(1,5),FN(1,6),FN(1,7),
     1 FN(1,8),FN(1,9),FN(1,10),FN(1,11),FN(1,12)/34.726685,34.551025,
     2 34.463531,34.503052,34.642029,34.806015,34.975433,35.352448,
     3 35.620544,35.566254,35.252518,34.667648/
      DATA GN(1,1),GN(1,2),GN(1,3),GN(1,4),GN(1,5),GN(1,6),GN(1,7),
     1 GN(1,8),GN(1,9),GN(1,10),GN(1,11),GN(1,12)/-0.11545753,
     2 -0.082896233,-0.014968872,0.058553696,0.094157219,0.096733093,
     3 0.10424614,0.10685921,0.034598351,-0.057549477,-0.12745190,
     4 -0.22149563/
      DATA XN(2,1),XN(2,2),XN(2,3),XN(2,4),XN(2,5),XN(2,6),XN(2,7),
     1 XN(2,8),XN(2,9)/1.7799997,5.1999969,8.6199951,12.039993,
     2 15.459999,18.879990,22.299988,25.719986,29.139999/
      DATA FN(2,1),FN(2,2),FN(2,3),FN(2,4),FN(2,5),FN(2,6),FN(2,7),
     1 FN(2,8),FN(2,9)/34.699966,34.441177,34.607269,34.980515,
     2 35.330429,35.642120,35.758163,35.500107,34.654861/
      DATA GN(2,1),GN(2,2),GN(2,3),GN(2,4),GN(2,5),GN(2,6),GN(2,7),
     1 GN(2,8),GN(2,9)/-0.084634781,-0.023357391,0.096752167,
     2 0.10944939,0.099792480,0.071731567,-0.011492729,-0.15031433,
     3 -0.35505390/
      DATA XN(3,1),XN(3,2),XN(3,3),XN(3,4),XN(3,5),XN(3,6),XN(3,7),
     1 XN(3,8),XN(3,9),XN(3,10),XN(3,11),XN(3,12)/1.8500004,3.4937487,
     2 5.1374979,6.7812462,8.4249954,10.068741,11.712494,14.999992,
     3 18.287476,21.574982,24.862488,28.149994/
      DATA FN(3,1),FN(3,2),FN(3,3),FN(3,4),FN(3,5),FN(3,6),FN(3,7),
     1 FN(3,8),FN(3,9),FN(3,10),FN(3,11),FN(3,12)/34.682465,34.517578,
     2 34.406326,34.443558,34.561661,34.729767,34.925735,35.267654,
     3 35.553070,35.674911,35.487518,34.840240/
      DATA GN(3,1),GN(3,2),GN(3,3),GN(3,4),GN(3,5),GN(3,6),GN(3,7),
     1 GN(3,8),GN(3,9),GN(3,10),GN(3,11),GN(3,12)/-0.090103149,
     2 -0.097715378,-0.022984505,0.054557800,0.088250160,0.11484337,
     3 0.11683750,0.096542358,0 069462776,-0.0027217865,-0.11839390,
     4 -0.28538132/
      DATA XN(4,1),XN(4,2),XN(4,3),XN(4,4),XN(4,5),XN(4,6),XN(4,7),
     1 XN(4,8),XN(4,9),XN(4,10),XN(4,11)/1.1899996,2.7418737,4.2937479,
```

```
2 5.8456221,7.3974972,10.501244,13.604996,16.708740,19.812500,
3 22.916245,26.020004/
 DATA FN(4,1),FN(4,2),FN(4,3),FN(4,4),FN(4,5),FN(4,6),FN(4,7),
1 FN(4,8),FN(4,9),FN(4,10),FN(4,11)/34.720779,34.626480,34.494614,
2 34.472565,34.548004,34.888580,35.243362,35.510086,35.633240,
3 35.589767,35.443451/
 DATA GN(4,1),GN(4,2),GN(4,3),GN(4,4),GN(4,5),GN(4,6),GN(4,7),
1 GN(4,8),GN(4,9),GN(4,10),GN(4,11)/0.11289215,-0.12562466,
2 -0.047614098,0.018503189,0.076808929,0.12305641,0.10305786,
3 0.065424919,0.012089729,-0.036752701,-0.048524857/
 DATA XN(5,1),XN(5,2),XN(5,3),XN(5,4),XN(5,5),XN(5,6),XN(5,7),
1 XN(5,8),XN(5,9)/1.8999996,4.9149990,7.9299994,10.944992,
2 13.959999,16.974991,19.989990,23.004990,26.020004/
 DATA FN(5,1),FN(5,2),FN(5,3),FN(5,4),FN(5,5),FN(5,6),FN(5,7),
1 FN(5,8),FN(5,9)/34.687988,34.472916,34.588760,34.911652,
2 35.253723,35.530823,35.700470,35.715652,35.457870/
 DATA GN(5,1),GN(5,2),GN(5,3),GN(5,4),GN(5,5),GN(5,6),GN(5,7),
1 GN(5,8),GN(5,9)/-0.072339058,-0.028326035,0.086900711,0.11726761,
2 0.10568237,0.076093674,0.034471512,-0.030061722,-0.15561867/
 DATA XN(6,1),XN(6,2),XN(6,3),XN(6,4),XN(6,5)/1.8500004,7.8174982,
1 13.784996,19.752487,25.720001/
 DATA FN(6,1),FN(6,2),FN(6,3),FN(6,4),FN(6,5)/34.691071,34.583099,
1 35.247391,35.713013,35.447403/
 DATA GN(6,1),GN(6,2),GN(6,3),GN(6,4),GN(6,5)/-0.13153839,
1 0.075304031,0.11000633,0.052697182,-0.22023773/
 DATA XN(7,1),XN(7,2),XN(7,3),XN(7,4),XN(7,5),XN(7,6),XN(7,7),
1 XN(7,8),XN(7,9)/1.1099997,3.5224981,5.9349966,8.3474884,
2 10.759995,13.172493,15.584999,17.997498,20.410004/
 DATA FN(7,1),FN(7,2),FN(7,3),FN(7,4),FN(7,5),FN(7,6),FN(7,7),
1 FN(7,8),FN(7,9)/34.728088,34.538361,34.459381,34.632278,
2 34.937805,35.236908,35.452240,35.554504,35.544281/
 DATA GN(7,1),GN(7,2),GN(7,3),GN(7,4),GN(7,5),GN(7,6),GN(7,7),
1 GN(7,8),GN(7,9)/0.044359207,-0.10148716,0.027439117,0.10853386,
2 0.13336277,0.10989761,0.066784859,0.017894745,-0.023929596/
 DATA XN(8,1),XN(8,2),XN(8,3),XN(8,4),XN(8,5),XN(8,6),XN(8,7),
1 XN(8,8),XN(8,9)/1.1099997,4.0724974,7.0349951,9.9974899,
2 12.959991,15.92249[illegible] 18.884995,21.847488,24.809998/
 DATA FN(8,1),FN(8,[illegible]N(8,3),FN(8,4),FN(8,5),FN(8,6),FN(8,7),
1 FN(8,8),FN(8,9)/34.742035,34.507553,34.523254,34.843521,
2 35.205383,35.453888,35.580109,35.633163,35.646423/
 DATA GN(8,1),GN(8,2),GN(8,3),GN(8,4),GN(8,5),GN(8,6),GN(8,7),
1 GN(8,8),GN(8,9)/-0.027276993,-0.065916061,0.069396019,
2 0.12857723,0.10705471,0.061277390,0.027302742,0.011056900,
3 -0.0043754578/
 LAT = DBLE(LAT4)
 LONG = DBLE(LONG4)
 T = DBLE(T4)
 IF (LAT.LE.25..AND.LONG.LE.160.) J = 1
 IF (LAT.LE.25..AND.LONG.GT.160..AND.LONG.LE.170.) J = 2
 IF (LAT.LE.25..AND.LONG.GT.170.) J = 3
 IF (LAT.GT.25..AND.LAT.LE.35..AND.LONG.LE.160.) J=4
 IF (LAT.GT.25..AND.LAT.LE.35..AND.LONG.GT.160..AND.LONG.LE.170.)
1 J = 5
 IF (LAT.GT.25..AND.LAT.LE.35..AND.LONG.GT.170.) J = 6
 IF (LAT.GT.35..AND.LONG.LE.160.) J = 7
 IF (LAT.GT.35..AND.LONG.GT.160..AND.LONG.LE.170.) J = 8
 N = NP(J)
```

```
      DO 1 I=1,N
      X(I) = XN(J,I)
      F(I) = FN(J,I)
    1 G(I) = GN(J,I)
      IF (T.GE.X(1).AND.T.LE.X(N)) GO TO 2
      IF (T.LT.X(1)) SAL = F(1) + (T - X(1))*G(1)
      IF (T.GT.X(N)) SAL = F(N) + (T - X(N))*G(N)
      RETURN
    2 SAL = TG01BD(-1,N,X,F,G,T)
      RETURN
      END
```

V.9 Subroutine PLOT1

```
      SUBROUTINE PLOT1(DEPTH,TEMP,SAL,SIGT,VELOC,L,IJ,ISCALE)
      DIMENSION DEPTH(200), TEMP(200),SAL(200),SIGT(200),VELOC(200),
     1    T(200),D(200),S(200),V(200),SG(200),Z1(5),Z2(5),ZP(5)
      DATA Z1/' 500',' 375',' 250',' 125',' 0  '/,
     1  Z2/'1000',' 750',' 500',' 250',' 0  '/
      CALL PLOTS(IBUF,NO,NUM)
                                              IF(ISCALE.EQ.2) GO TO 20
         DO 10 I=1,5
 10      ZP(I) = Z1(I)
                                                          GO TO 40
 20      DO 30 I=1,5
 30      ZP(I) = Z2(I)
 40   CONTINUE
      DEPTH(L+1)=0.
      DEPTH(L+2)= 125.* FLOAT(ISCALE)
      TEMP(L+1)=0.
      TEMP(L+2)=10.
      SAL(L+1)=34.0
      SAL(L+2)=0.6666667
      SIGT(L+1)=23.
      SIGT(L+2)=1.3333333
      VELOC(L+1)=1480.
      VELOC(L+2)=26.6666667
      CALL PLOT(0.,8.25,22)
      CALL PLOT(11.65,0.,22)
      CALL PLOT(0.,-8.25,22)
      CALL PLOT(-11.65,0.,22)
      CALL PLOT (1.,1.0,23)
      K=1
      CALL PLOT(0.,3.,2)
      CALL PLOT(-0.05,3.,2)
      CALL SYMBOL(-0.1,2.9,.105,2H30,90.,2)
      CALL PLOT(0.,2.,3)
      CALL PLOT(-.05,2.,2)
      CALL SYMBOL(-0.1,1.9,.105,2H20,90.,2)
      CALL PLOT(0.,1.,3)
      CALL PLOT(-0.05,1.,2)
      CALL SYMBOL(-0.1,0.9,.105,2H10,90.,2)
      CALL PLOT (0.,0.,3)
```

```
      CALL PLOT (-0.05,0.,2)
      CALL SYMBOL(-0.1,-0.05,.105,2H00,90.,2)
      CALL SYMBOL(-0.3,0.72,.105,15HTEMPERATURE (C),90.,15)
      CALL PLOT(0.,0.,3)
   50 CALL PLOT(4.,0.,2)
      CALL PLOT(4.,-0.05,2)
      CALL SYMBOL(4.20,-0.1,.105,ZP(1),180.,4)
      CALL PLOT(3.,0.,3)
      CALL PLOT(3.,-0.05,2)
      CALL SYMBOL(3.20,-0.1,.105,ZP(2),180.,4)
      CALL PLOT(2.,0.,3)
      CALL PLOT(2.,-0.05,2)
      CALL SYMBOL(2.15,-0.1,.105,ZP(3),180.,4)
      CALL PLOT(1.,0.,3)
      CALL PLOT(1.,-0.05,2)
      CALL SYMBOL(1.15,-0.1,.105,ZP(4),180.,4)
      CALL PLOT(0.,0.,3)
      CALL PLOT(0.,-0.05,2)
      CALL SYMBOL(+0.05,-0.1,.105,ZP(5),180.,4)
      CALL SYMBOL(2.47,-0.30,.105,9HDEPTH (M),180.,9)
                                                  GO TO (60,70,80,90),K
   60 CALL LINE(DEPTH,TEMP,L,1,0,0)
      CALL PLOT (0.,3.9,23)
      CALL PLOT (0.,3.,2)
      CALL PLOT (-0.05,3.,2)
      CALL SYMBOL(-0.1,2.9,.105,2H36,90.,2)
      CALL PLOT(0.,2.25,3)
      CALL PLOT(-0.05,2.25,2)
      CALL SYMBOL(-0.1,2.15,.105,4H35.5,90.,4)
      CALL PLOT(0.,1.5,3)
      CALL PLOT(-0.05,1.5,2)
      CALL SYMBOL(-0.1,1.4,.105,2H35,90.,2)
      CALL PLOT(0.,0.75,3)
      CALL PLOT(-0.05,0.75,2)
      CALL SYMBOL(-0.1,0.65,.105,4H34.5,90.,4)
      CALL PLOT(0.,0.,3)
      CALL PLOT (-0.05,0.,2)
      CALL SYMBOL(-0.1,-0.10,.105,2H34,90.,2)
      CALL SYMBOL(-0.3,0.77,.105,14HSALINITY (PPT),90.,14)
      CALL PLOT (0.,0.,3)
      K=K+1
                                                            GO TO 50
   70 CONTINUE
      CALL LINE (DEPTH,SAL,L,1,0,0)
      CALL PLOT(5.,0.,23)
      CALL PLOT(0.,3.,2)
      CALL PLOT(-0.05,3.,2)
      CALL SYMBOL(-0.1,2.9,.105,2H27,90.,2)
      CALL PLOT(0.,2.25,3)
      CALL PLOT(-0.05,2.25,2)
      CALL SYMBOL(-0.1,2.15,.105,2H26,90.,2)
      CALL PLOT(0.,1.5,3)
      CALL PLOT(-0.05,1.5,2)
      CALL SYMBOL(-0.1,1.4,.105,2H25,90.,2)
      CALL PLOT(0.,0.75,3)
      CALL PLOT(-0.05,0.75,2)
      CALL SYMBOL(-0.1,0.65,.105,2H24,90.,2)
```

```
      CALL PLOT(0.,0.,3)
      CALL PLOT(-.05,0.,2)
      CALL SYMBOL(-0.1,-0.05,.105,2H23,90.,2)
      CALL SYMBOL(-0.3,1.13,.105,7HSIGMA-T,90.,7)
      CALL PLOT(0.,0.,23)
      K=K+1
                                                            GO TO 50
   80 CONTINUE
      CALL LINE(DEPTH,SIGT,L,1,0,0)
      CALL PLOT(0.,-3.9,23)
      CALL PLOT(0.,3.,2)
      CALL PLOT(-0.05,3.,2)
      CALL SYMBOL(-0.1,2.8,.105,4H1560,90.,4)
      CALL PLOT(0.,2.25,3)
      CALL PLOT(-0.05,2.25,2)
      CALL SYMBOL(-0.1,2.15,.105,4H1540,90.,4)
      CALL PLOT(0.,1.5,3)
      CALL PLOT(-0.05,1.5,2)
      CALL SYMBOL(-0.1,1.3,.105,4H1520,90.,4)
      CALL PLOT(0.,0.75,3)
      CALL PLOT(-0.05,0.75,2)
      CALL SYMBOL(-0.1,0.55,.105,4H1500,90.,4)
      CALL PLOT(0.,0.,3)
      CALL PLOT(-0.05,0.,2)
      CALL SYMBOL(-0.1,-0.20,.105,4H1480,90.,4)
      CALL SYMBOL(-0.3,0.5,.105,20HSOUND VELOCITY (M/S),90.,20)
      CALL PLOT(0.,0.,3)
      K = K+1
                                                            GO TO 50
   90 CALL LINE(DEPTH,VELOC,L,1,0,0)
      CALL SYMBOL(5.,0.75,.21,17HCONSECUTIVE NO.  ,90.,17)
      AIJ=DFLOAT(IJ)
      CALL NUMBER(5.,999.,.21,AIJ,90.,-1)
      CALL ENDPLT
      RETURN
      END
```

V.10 Subroutine LNGPLT (additional ENTRY ADDPLT)

```
      SUBROUTINE LNGPLT(SV,UPI,XTITLE,XARRAY,YARRAY,L,IJ,ICALL,MANY)
      REAL*4 XTITLE(5),YTITLE(4),XARRAY(150),YARRAY(150)
      DATA YTITLE/'DEPT','H - ','METR','ES  '/
      IF (ICALL.EQ.1) CALL PLOTS(IBUF,NO,NUM)
C
C DESIGNATES ORIGIN
C
      CALL PLOT( 1.   , 9.   ,23)
C
C
C PLOT VERTICAL SCALE
C
      CALL PLOT(-0.1 , 0.   ,2)
      CALL PLOT( 0.   , 0.   ,2)
```

```
      CALL PLOT( 0.   ,-0.5 ,2)
      CALL PLOT( 0.   ,-0.5 ,2)
      X = 0.
      Y = -1.
         DO 10 I = 1,8
         CALL PLOT(X,Y,2)
         X = -0.1
         CALL PLOT(X,Y,2)
         X = 0
         CALL PLOT(X,Y,2)
         Y = Y-0.5
         CALL PLOT(X,Y,2)
         X = -0.05
         CALL PLOT(X,Y,2)
         X = 0
         CALL PLOT(X,Y,2)
         Y = Y-0.5
   10    CONTINUE
      CALL PLOT(X,Y,2)
      X = -0.1
      CALL PLOT(X,Y,2)
C
C PRINT VERTICAL TITLE
C
      CALL SYMBOL(-0.85,-5.48,0.14,YTITLE,90.,16)
C
C PLOT NUMBERS ON VERTICAL SCALE.
C PLOT NUMBERS SUB-ROUTINE CALLS 'PLOT SYMBOL' AND REFERS TO
C X & Y ERRORS AS BEING IN PLOT SYMBOL.
C
      FPN = 0.
      CALL NUMBER(-0.34,-0.07,0.14,FPN,0.,-1)
      IFPN = FPN+100.
C
C RE-DEFINE Y AS ZERO
C
      Y = 0
         DO 20 I =1,9
         Y = Y-1
         FPN = IFPN
         CALL NUMBER(-0.62,Y,0.14,FPN,0.,-1)
         IFPN = IFPN+100
   20    CONTINUE
C
C PLOT HORIZONTAL SCALE
C
      CALL PLOT(0.,0. ,3)
      CALL PLOT(0.,0.1,2)
      CALL PLOT(0.,0. ,2)
      X = 0.
      Y = 0.
         DO 30 I = 1,3
         X = X+1.0
         CALL PLOT(X,Y,2)
         Y = Y+0.1
         CALL PLOT(X,Y,2)
         Y = Y-0.1
```

```
   30    CALL PLOT(X,Y,2)
C
C PRINT HORIZONTAL TITLE
C
      CALL PLOT(0.,0.,3)
      CALL SYMBOL(0.1,0.75,0.14,XTITLE,0.,20)
C
C PLOT NUMBERS ON HORIZONTAL SCALE. ONLY THE START VALUE
C AND THE NEXT THREE VALUES ARE REQUIRED.
C
      ISV = SV
      IUPI = UPI
      IFPN = ISV-IUPI
         DO 40 I = 1,4
         XI = I-1
         IFPN = IFPN+IUPI
         IF(IFPN.GE.0.AND.IFPN.LT.10)    XM = XI-0.07
         IF(IFPN.GE.10.AND.IFPN.LT.100)  XM = XI-0.14
         IF(IFPN.GE.100.AND.IFPN.LT.1000) XM = XI-0.21
         IF(IFPN.GE.1000.AND.IFPN.LT.10000) XM = XI-0.28
         FPN = IFPN
   40    CALL NUMBER(XM,0.2,0.14,FPN,0.,-1)
C
C     MOVE X ORIGIN PROGRESSIVELY TO THE RIGHT AND EXTEND X GRID
C
      ENTRY ADDPLT(XARRAY,YARRAY,L,IJ,ICALL)
                                          IF(ICALL.EQ.1) GO TO 50
      CALL PLOT(0.5,0.0,23)
      CALL PLOT(2.5,0.0, 3)
      CALL PLOT(3.0,0.0, 2)
      CALL PLOT(3.0,0.1, 2)
C
C TO PLOT EACH TRACE.
C
   50 XARRAY(L+1) = SV
      XARRAY(L+2) = UPI
      YARRAY(L+1) = 0.
      YARRAY(L+2) = -100.
      CALL LINE(XARRAY,YARRAY,L,1,0,0)
C
C TO PLOT A SERIAL NO. AT THE END OF EACH TRACE
C
      FIJ = IJ
      X = (XARRAY(L)-SV)/UPI
      Y = YARRAY(L)/(-100.)-0.24
      IF(FIJ.GE.0.AND.FIJ.LT.10)    X = X-0.07
      IF(FIJ.GE.10.AND.FIJ.LT.100)  X = X-0.14
      IF(FIJ.GE.100.AND.FIJ.LT.1000) X = X-0.21
      CALL NUMBER(X,Y,0.14,FIJ,0.,-1)
      IF (ICALL.EQ.MANY) CALL ENDPLT
      RETURN
      END
```

APPENDIX VI SAMPLE PROGRAMME OUTPUT

WSRL CRUISE TASMAN SEA MP1/79/D1
XBT NUMBER 1

DATE	TIME	LONGITUDE	LATITUDE
08.03.79	1400	151.92 DEG.E	33.72 DEG.S

SONIC DEPTH	AIR TEMPERATURE (DEG.C)		WIND		ATMOS.PRESS
[illegible].M	WET 17.8	DRY 22.8	DIR 190	12 KNOTS	1018.1 MB

DEPTH M	TEMPERATURE C	SALINITY PPT	DYNAMIC HT. ANOMALY DYNM	DELTA CM**3/GM	DENSITY GM/CM**3	SIGMA T (GM/CM**3) /1000	ALPHA *10**6/ DEG.C	BETA *10**6/ BAR	SOUND SPEED M/SEC	PRESSURE BAR	SPECIFIC HEAT J/G/DEG
0.	25.20	35.48	0.0	0.004233	1.023649	23.649	298.9	0.0	1545.55	0.0	3.9958
5.	25.18	35.49	0.021	0.004228	1.023677	23.656	298.7	42.08	1545.58	0.501	3.9956
10.	25.16	35.49	0.042	0.004224	1.023705	23.663	298.6	42.08	1545.61	1.003	3.9955
15.	24.75	35.51	0.063	0.004092	1.023868	23.803	295.6	42.11	1544.57	1.504	3.9950
20.	24.13	35.54	0.083	0.003894	1.024098	24.013	290.9	42.15	1542.93	2.006	3.9943
25.	23.43	35.57	0.102	0.003677	1.024350	24.242	285.5	42.21	1541.03	2.507	3.9934
30.	22.67	35.60	0.120	0.003448	1.024614	24.485	279.6	42.27	1538.92	3.009	3.9926
35.	21.86	35.62	0.137	0.003215	1.024882	24.731	273.3	42.34	1536.60	3.511	3.9917
40.	21.14	35.63	0.153	0.003013	1.025114	24.940	267.6	42.40	1534.50	4.013	3.9909
45.	20.33	35.64	0.167	0.002808	1.025358	25.162	261.1	42.48	1532.06	4.515	3.9901
50.	19.77	35.63	0.181	0.002671	1.025525	25.307	256.6	42.54	1530.37	5.017	3.9895
55.	19.38	35.63	0.194	0.002581	1.025643	25.403	253.4	42.58	1529.20	5.520	3.9891
60.	19.00	35.62	0.207	0.002496	1.025758	25.495	250.3	42.62	1528.04	6.022	3.9886
65.	18.44	35.60	0.219	0.002375	1.025908	25.622	245.7	42.68	1526.27	6.524	3.9881
70.	17.88	35.58	0.231	0.002262	1.026052	25.743	241.0	42.74	1524.47	7.027	3.9876
75.	17.39	35.55	0.242	0.002167	1.026175	25.845	236.9	42.80	1522.88	7.529	3.9872
80.	17.33	35.55	0.253	0.002157	1.026209	25.856	236.4	42.80	1522.76	8.032	3.9870
85.	17.10	35.53	0.263	0.002115	1.026277	25.902	234.5	42.83	1522.05	8.534	3.9868
90.	16.71	35.51	0.274	0.002047	1.026373	25.975	231.2	42.88	1520.77	9.037	3.9864
95.	16.36	35.49	0.284	0.001987	1.026460	26.039	228.2	42.92	1519.62	9.539	3.9861
100.	16.00	35.46	0.294	0.001929	1.026545	26.102	225.1	42.96	1518.42	10.042	3.9858
110.	15.44	35.42	0.313	0.001842	1.026684	26.196	220.3	43.03	1516.57	11.047	3.9853
120.	14.93	35.37	0.331	0.001769	1.026809	26.275	215.8	43.10	1514.87	12.053	3.9848
130.	14.57	35.34	0.348	0.001722	1.026906	26.327	212.7	43.14	1513.70	13.058	3.9844
140.	14.21	35.30	0.366	0.001676	1.027002	26.378	209.6	43.19	1512.52	14.064	3.9841
150.	13.93	35.28	0.382	0.001642	1.027085	26.416	207.2	43.22	1511.64	15.069	3.9837
160.	13.74	35.26	0.399	0.001620	1.027155	26.441	205.6	43.24	1511.08	16.075	3.9834
170.	13.56	35.24	0.415	0.001600	1.027225	26.464	204.1	43.26	1510.56	17.080	3.9831
180.	13.37	35.22	0.431	0.001580	1.027293	26.488	202.4	43.28	1510.00	18.086	3.9828
190.	13.19	35.20	0.447	0.001561	1.027361	26.510	200.9	43.30	1509.48	19.092	3.9825
200.	13.00	35.18	0.462	0.001542	1.027428	26.532	199.3	43.32	1508.91	20.097	3.9822
210.	12.86	35.16	0.478	0.001529	1.027490	26.548	198.1	43.33	1508.53	21.103	3.9819
220.	12.72	35.15	0.493	0.001516	1.027551	26.565	197.0	43.34	1508.16	22.109	3.9816
230.	12.58	35.13	0.508	0.001503	1.027613	26.581	195.8	43.35	1507.78	23.115	3.9813
240.	12.44	35.12	0.523	0.001490	1.027674	26.596	194.7	43.37	1507.39	24.120	3.9810
250.	12.30	35.10	0.538	0.001478	1.027733	26.610	193.5	43.38	1507.01	25.126	3.9807
260.	12.17	35.09	0.553	0.001467	1.027793	26.625	192.4	43.39	1506.66	26.132	3.9804
270.	12.04	35.07	0.568	0.001456	1.027852	26.638	191.3	43.40	1506.32	27.138	3.9801
280.	11.86	35.05	0.582	0.001441	1.027916	26.656	189.8	43.42	1505.77	28.144	3.9798
290.	11.65	35.03	0.597	0.001422	1.027983	26.677	187.9	43.45	1505.10	29.150	3.9795
300.	11.45	35.00	0.611	0.001405	1.028048	26.696	186.2	43.47	1504.46	30.156	3.9792
310.	11.24	34.78	0.625	0.001389	1.028113	26.715	184.3	43.50	1503.78	31.161	3.9789
320.	11.04	34.95	0.639	0.001373	1.028177	26.733	182.5	43.52	1503.14	32.167	3.9785
330.	10.91	34.94	0.652	0.001363	1.028234	26.745	181.4	43.54	1502.77	33.173	3.9782
340.	10.81	34.93	0.666	0.001358	1.028288	26.752	180.6	43.54	1502.53	34.179	3.9779
350.	10.70	34.91	0.680	0.001350	1.028343	26.762	179.7	43.55	1502.25	35.185	3.9776
360.	10.38	34.87	0.693	0.001326	1.028417	26.788	176.8	43.60	1501.10	36.191	3.9773
370.	10.06	34.83	0.706	0.001302	1.028488	26.813	173.8	43.65	1499.95	37.197	3.9770
380.	9.94	34.82	0.720	0.001296	1.028543	26.821	172.8	43.66	1499.61	38.204	3.9767
390.	9.86	34.81	0.733	0.001291	1.028596	26.828	172.1	43.67	1499.45	39.210	3.9764
400.	9.78	34.80	0.746	0.001287	1.028647	26.834	171.5	43.67	1499.28	40.216	3.9761
410.	9.71	34.79	0.758	0.001284	1.028698	26.838	171.0	43.67	1499.15	41.222	3.9759
420.	9.63	34.78	0.771	0.001280	1.028749	26.844	170.4	43.68	1498.98	42.228	3.9756
430.	9.55	34.77	0.784	0.001276	1.028801	26.850	169.8	43.68	1498.81	43.234	3.9753
440.	9.48	34.76	0.797	0.001273	1.028852	26.855	169.2	43.68	1498.69	44.240	3.9750
450.	9.40	34.75	0.810	0.001269	1.028903	26.860	168.6	43.69	1498.52	45.246	3.9747
460.	9.27	34.74	0.823	0.001260	1.028959	26.870	167.5	43.70	1498.14	46.253	3.9744
470.	9.14	34.72	0.835	0.001253	1.029015	26.878	166.4	43.72	1497.75	47.259	3.9741
480.	9.01	34.71	0.848	0.001245	1.029071	26.888	165.3	43.73	1497.37	48.265	3.9738
490.	8.93	34.70	0.860	0.001240	1.029122	26.894	164.6	43.73	1497.20	49.271	3.9735
500.	8.85	34.69	0.873	0.001236	1.029174	26.899	164.0	43.74	1497.02	50.277	3.9732
510.	8.78	34.68	0.885	0.001233	1.029225	26.904	163.5	43.74	1496.89	51.284	3.9729
520.	8.70	34.67	0.898	0.001229	1.029277	26.910	162.9	43.75	1496.72	52.290	3.9726
530.	8.63	34.66	0.910	0.001225	1.029327	26.915	162.3	43.75	1496.58	53.296	3.9723
540.	8.55	34.66	0.922	0.001221	1.029380	26.920	161.7	43.75	1496.41	54.302	3.9720
550.	8.47	34.65	0.934	0.001216	1.029431	26.926	161.1	43.76	1496.23	55.309	3.9717
560.	8.40	34.64	0.947	0.001213	1.029483	26.931	160.6	43.76	1496.10	56.315	3.9714
570.	8.32	34.63	0.959	0.001208	1.029534	26.937	160.0	43.77	1495.92	57.321	3.9711
580.	8.24	34.62	0.971	0.001204	1.029587	26.942	159.3	43.77	1495.75	58.327	3.9708
590.	8.17	34.62	0.983	0.001200	1.029637	26.947	158.8	43.77	1495.61	59.334	3.9705
600.	8.09	34.61	0.995	0.001194	1.029691	26.954	158.2	43.78	1495.44	60.340	3.9702
610.	8.02	34.60	1.007	0.001191	1.029742	26.958	157.7	43.78	1495.30	61.346	3.9699
620.	7.69	34.57	1.019	0.001165	1.029817	26.983	154.5	43.84	1494.05	62.353	3.9695
630.	7.35	34.54	1.031	0.001132	1.029899	27.015	150.7	43.90	1492.57	63.359	3.9691
640.	6.96	34.52	1.042	0.001101	1.029979	27.044	147.3	43.96	1491.21	64.365	3.9692
650.	6.76	34.51	1.053	0.001083	1.030046	27.062	145.4	43.99	1490.50	65.373	3.9688

READY

APPENDIX VII SAMPLE CARD IMAGE INPUT FILE

```
       03
WSRL CRUISE TASMAN SEA MP1/79/D1
08/03/79    1400      151.92 DEG E       33.72 DEG S
  657.M      WET 17.8 DRY 22.8  DIR 190 12 KNOTS    1018.1MB
  1   76
  0.0   25.20   5.00 25.18 10.00 25.16 15.00 24.75 20.00 24.13 25.00 23.43
 30.00 22.67 35.00 21.86 40.00 21.14 45.00 20.33 50.00 19.77 55.00 19.38
 60.00 19.00 65.00 18.44 70.00 17.88 75.00 17.39 80.00 17.33 85.00 17.10
 90.00 16.71 95.00 16.36100.00 16.00110.00 15.44120.00 14.93130.00 14.57
140.00 14.21150.00 13.93160.00 13.74170.00 13.56180.00 13.37190.00 13.19
200.00 13.00210.00 12.86220.00 12.72230.00 12.58240.00 12.44250.00 12.30
260.00 12.17270.00 12.04280.00 11.86290.00 11.65300.00 11.45310.00 11.24
320.00 11.04330.00 10.91340.00 10.81350.00 10.70360.00 10.38370.00 10.06
380.00  9.94390.00  9.86400.00  9.78410.00  9.71420.00  9.63430.00  9.55
440.00  9.48450.00  9.40460.00  9.27470.00  9.14480.00  9.01490.00  8.93
500.00  8.85510.00  8.78520.00  8.70530.00  8.63540.00  8.55550.00  8.47
560.00  8.40570.00  8.32580.00  8.24590.00  8.17600.00  8.09610.00  8.02
620.00  7.69630.00  7.31640.00  6.96650.00  6.76
WSRL CRUISE TASMAN SEA MP1/79/D1
 8/03/79    1500      152.17 DEG E       33.68 DEG S
 1808.M      WET 17.8 DRY 22.8  DIR 170 14 KNOTS    1018.1MB
  2   99
  0.0   25.80   5.00 25.79 10.00 25.78 15.00 25.77 20.00 25.76 25.00 25.75
 30.00 25.74 35.00 25.73 40.00 25.72 45.00 25.71 50.00 25.70 55.00 24.33
 60.00 22.78 65.00 22.22 70.00 21.70 75.00 21.62 80.00 21.53 85.00 21.33
 90.00 21.06 95.00 20.76100.00 20.47110.00 19.83120.00 19.00130.00 17.79
140.00 17.07150.00 16.18160.00 15.68170.00 15.28180.00 14.75190.00 13.97
200.00 13.72210.00 13.47220.00 13.22230.00 12.99240.00 12.90250.00 12.80
260.00 12.42270.00 12.04280.00 11.83290.00 11.63300.00 11.44310.00 11.25
320.00 11.06330.00 10.90340.00 10.75350.00 10.60360.00 10.41370.00 10.22
380.00 10.04390.00  9.84400.00  9.64410.00  9.44420.00  9.24430.00  9.04
440.00  8.87450.00  8.70460.00  8.61470.00  8.52480.00  8.42490.00  8.33
500.00  8.24510.00  8.15520.00  8.06530.00  7.97540.00  7.88550.00  7.80
560.00  7.72570.00  7.64580.00  7.55590.00  7.47600.00  7.39610.00  7.31
620.00  7.22630.00  7.14640.00  7.06650.00  6.98660.00  6.90670.00  6.81
680.00  6.73690.00  6.65700.00  6.57710.00  6.49720.00  6.41730.00  6.33
740.00  6.25750.00  6.17760.00  6.09770.00  6.01780.00  5.94790.00  5.88
800.00  5.81810.00  5.75820.00  5.69830.00  5.62840.00  5.56850.00  5.49
860.00  5.43870.00  5.36880.00  5.30
WSRL CRUISE TASMAN SEA MP1/79/D1
 8/03/79    1600      152.36 DEG E       33.64 DEG S
 2848.M      WET 17.8 DRY 22.8  DIR 150 12 KNOTS    1016.3MB
  3   96
  0.0   25.60   5.00 25.55 10.00 25.51 15.00 25.46 20.00 25.41 25.00 25.37
 30.00 25.32 35.00 24.33 40.00 23.75 45.00 23.44 50.00 23.13 55.00 22.86
 60.00 22.64 65.00 22.41 70.00 22.18 75.00 21.96 80.00 21.76 85.00 21.56
 90.00 21.36 95.00 21.16100.00 20.96110.00 20.54120.00 20.13130.00 19.63
140.00 19.11150.00 18.56160.00 18.00170.00 17.55180.00 17.09190.00 16.78
200.00 16.74210.00 16.59220.00 16.05230.00 15.67240.00 15.30250.00 14.90
260.00 14.63270.00 14.35280.00 14.08290.00 13.75300.00 13.39310.00 13.04
320.00 12.79330.00 12.56340.00 12.33350.00 12.10360.00 11.94370.00 11.76
380.00 11.57390.00 11.39400.00 11.20410.00 11.02420.00 10.71430.00 10.39
440.00 10.06450.00 10.00460.00  9.81470.00  9.62480.00  9.43490.00  9.25
```

500.00	9.06510.00	8.93520.00	8.82530.00	8.71540.00	8.61550.00	8.50
560.00	8.39570.00	8.29580.00	8.18590.00	8.07600.00	7.97610.00	7.88
620.00	7.78630.00	7.69640.00	7.59650.00	7.50660.00	7.41670.00	7.31
680.00	7.22690.00	7.12700.00	7.03710.00	6.96720.00	6.89730.00	6.83
740.00	6.76750.00	6.70760.00	6.63770.00	6.57780.00	6.51790.00	6.44
800.00	6.38810.00	6.31820.00	6.25830.00	6.19840.00	6.12850.00	6.06

APPENDIX VIII INPUT DATA FORMAT FOR AN XBT DATA POINT RECORD AS USED BY AODC

VIII.1 Input record format

Element Name and Level	Position Byte Nos	Number Bytes		Usage and Meaning of Element
File I.D.	1-2	2	Char(2)	File I.D. Always 17
QUADRT[1]	3	1	Char(1)	WMO 3333
TEN SQ[1]		3	Char(3)	Ten Degree Square (WMO)
FIVE SQ[1]	7	1	Char(1)	Five Degree Square
TWO SQ[1]	8-9	2	Char(2)	Two Degree Square
ONE SQ[1]	10-11	2	Char(2)	One Degree Square
DATE				
YEAR	12-15	4	Char(4)	Prefix '19'
MONTH	16-17	2	Char(2)	01-12
DAY	18-19	2	Char(2)	01-31
TIME				
HOUR	20-21	2	Char(2)	00-23
MIN	22-23	2	Char(2)	00-59
REF. I.D.				
CNTRY	24-26	3	Char(3)	NODC CODES
REF. NO	27-31	5	Char(5)	
CONSEC	32-34	3	Char(3)	
SHIP	35-40	6	Char(6)	
LATITUDE				
LAT. DEG	41-42	2	Char(2)	00-90
LAT. MIN	43-44	2	Char(2)	00-59
LAT. HEM	45	1	Char(1)	N or S
LONGITUDE				
LONG DEG	46-48	3	Char(3)	000-179

LONG MIN	49-50	2	Char(2)	00-59
LONG HEM	51	1	Char(1)	E or W
NODC CODES				
BOTTOM	52	1	Char(1)	B = probe hit bottom, blank = did not
DIGMTH[2]	53-54	2	Char(2)	Method of digitisation
INTER[2]	55-56	2	Char(2)	Interval of digitisation
TRESTO[2]	57-58	2	Char(2)	Method of treatment & storage of initial points.
OPERATOR				
INIT	59-61	3	Char(3)	Operator's Initials
TRIAL	62	1	Char(1)	Number of attempts at digitising trace.
CALDEP	63-65	3	Char(3)	Depth of calibration tick in Units of analogue grid. Negative depth value for calibration tick above surface, Positive depth value for calibration tick below surface.
CALTEM	66-68	3	Char(3)	Temperature of calibration tick in units of analogue grid. 16.7° is nil-calibration value.
INSTRUMENT	69	1	Char(1)	1=XBT, 2=HXBT, 3=SXBT, 4=AXBT
GRID/3[3]	70	1	Char(1)	Grid codes of instrument 1-9.
ORIG CR NO	71-78	8	Char(8)	Originators cruise number.
DNP	79	1	Char(1)	Declared National Program
SKIP	80	1	Char(1)	Blank
LENGTH	81-84	4	Char(4)	Number of temperature values.
DEPTH & TEMP				
SURTEM	85-88	4	Char(4)	Temperature at zero depth.
DEPTH 1	89-92	4	Char(4)	First depth to whole metres.
TEMP 1	93-96	4	Char(4)	Temp at first depth.
DEPTH 2	97-100	4	Char(4)	Second depth.
TEMP 2	101	4	Char(4)	Temperature at second depth.

DEPTH (N)	4	Char(4)	Last depth	Position = (N-1) + 85
TEMP (N)	4	Char(4)	Last temperature	Position = (N-1) + 89

Notes:

1. The location of an XBT station on the Earth's surface is identified to within a 10° square using the WMO Code 3333 quadrant and 10° square numbering system. Under this system, position is designated by a four-digit number; the first digit identifies the quadrant of the globe (figure 8), and may take values of 1(NE), 3(SE), 5(SW) or 7(NW); the second digit is the tens digit of the latitude of the station; the third and fourth digits are the hundreds and tens digits of degrees of longitude. Position within a 10° square is identified using the modified Canadian subdivision systems; subdivisions of 5-, 2-, and 1-degree squares are coded as shown in figure 9.

2. See Section VIII.3 for codes.

3. See Section VIII.2 for codes.

VIII.2 BT instrument and grid code

Instrument and grid	Instrument code	Grid code
Shipboard XBT	1	
2500 foot (Ft & F)		1
750 metre (M & C)		2
1500 foot (Ft & F)		3
450 metre (M & C)		4
1830 metre (M & C)		5
Helicopter XBT	2	
Unknown		6
Submarine XBT	3	
Unknown		7
Airborne XBT (AXBT)	4	
1000 (Ft & F)		8

VIII.3 Digitisation method, interval of digitisation, and Data treatment and storage codes

I DIGITISATION METHOD	Code
a. Manual	01
b. A-D conversion from original	02
c. A-D conversion from copies	03
d. Optical scanning	04
e. Direct digital output	05
II INTERVAL OF DIGITISATION	Code
A. Fixed interval	
a. ≦1m; and ≦0.1°C	01
b. >1m but ≦3m; and ≦0.1°C	02
c. >3m but ≦6m; and ≦0.1°C	03
d. >6m; and ≦0.1°C	04
e. ≦1m; and ≦0.2°C	11
f. >1m but ≦3m; and ≦0.2°C	12
g. >3m but ≦6m; and ≦0.2°C	13
B. Variable (flexure points)	
a. Manually determined	31
b. Statistically determined	32
c. Physically determined	33
C. Combination of fixed and variable	
a. Every 3 ft to 900 ft then flexure points below 900 ft	
III TREATMENT AND STORAGE OF DIGITISED DATA	Code
A. Single digitisation.	
a. No treatment, stored as digitised	01
DATA COMPRESSION resulting in	
b. Fit within 0.05°C	02
c. Fit within 0.1°C	03
d. Fit within 0.2°C	04
e. Fit within 0.3°C	05
f. Fit within 0.7°C	06
B. Dual digitisation and averaging	
a. No treatment, stored as digitised	21
DATA COMPRESSION after averaging	
b. Fit within 0.05°C	22
c. Fit within 0.1°C	23
d. Fit within 0.2°C	24
e. Fit within 0.3°C	25
f. Fit within 0.5°C	26
C. Data points at fixed intervals or selected intervals retained and stored	27

APPENDIX IX HARWELL SUBROUTINES USED BY THE DATA REDUCTION PROGRAMME

The XBT data reduction programme uses various subroutines from the Harwell Subroutine Library for spline fitting, and for interpolation and quadrature using cubic spline fits. The following excerpts from the Harwell Subroutine Library User's Manual describe the functions and argument lists for the subroutines used.

IX.1 Subroutine TB04AD

1. Purpose

Given function values $f_1,f_2,\dots,f_n$ at points $x_1<x_2<\dots<x_n$ which need not be equally spaced, this routine finds a cubic spline $S(x)$ that interpolates the function values, ie

$$S(x_i) = f_i,\ i=1,2,\dots,n$$

where $S(x)$ has knots at the points $x_1,x_2,\dots,x_n$. The extra two degrees-of-freedom for such an interpolation are taken up by forcing the third derivative of $S(x)$ at the points x_2 and x_{n-1} to be continuous. $S(x)$ is defined on return from the routine by n, the knots x_i, its values f_i at the knots, and the values d_i of its first derivatives at the knots.

2. Argument list

```
SUBROUTINE TB04AD(N,X,F,D,W)
```

The arguments N, X and F must be set by the user before calling TB04AD.

N is INTEGER*4 and should be set to n, the number of points.

X is a REAL*8 array of length at least N containing the points x_i, $i=1,\dots,n$ (which are also the knots). These must be ordered such that $x_1<x_2<\dots<x_n$. If this condition is not fulfilled, W(1) is set to 1 and a diagnostic message is printed by the routine.

F is a REAL*8 array of length at least N which must contain the function values, $f_1,f_2,\dots,f_n$.

D is a REAL*8 array of length at least N in which the routine puts the values of the first derivatives of the spline $S(x)$ at the knots x_i.

W is a REAL*8 array of length at least 3*N used by the routine as work-space. W(1) is set to zero on a successful return and to 1 on a failure.

IX.2 Function TG01BD

1. Purpose

Given a cubic spline in terms of its knots, values and first derivative at the knots, this function calculates the value of the spline at any other point.

If the point at which the value is required lies outside the interval between the first and last knots, the value of the spline is set to zero.

2. Argument list

```
DOUBLE PRECISION FUNCTION TG01BD(I,N,X,F,D,X)
```

where N, X, F, and D take the values returned by TB04AD, and

X is REAL*8, and is the point at which the value of the spline is required.

I is INTEGER*4, and is a parameter which enables the function to make use of known information ie if I≧0, then the function will assume that it has been entered previously with a smaller value of X (this reduces the number of knot intervals to be searched for x). If I<0, the function searches the whole range for x.

IX.3 Function QG02AD

1. Purpose

Given a cubic spline $S(x)$ defined by knots x_i, function values, $S_i = S(x_i)$ and derivative values $g_i = dS(x_i)/dx$, $i=1,2,\ldots,n$, $n \geq 2$, and given integration limits a and b the routine will evaluate

$$Q = \int_a^b S(x)dx$$

The routine is not restricted to splines, and may be used with any piecewise cubic with continuous first derivative defined by its values and first derivative values at the joins.

2. Argument list

```
DOUBLE PRECISION FUNCTION QG02AD(A,B,N,X,F,D)
```

where N, X, F, and D take the values returned by TB04AD, and

A,B are REAL*8, and must be set by the user to the lower and upper limits of region of integration respectively. If either A or B is outside the range of the knots, the integral is calculated on the assumption

that $S(x)=0$ for $x<x_1$ and $x>x_n$. If A>B the sign of the integral is appropriately modified.

IX.4 Subroutine QG05AD

1. Purpose

To evaluate the definite integral

$$I(a,b;\ f) = \int_a^b f(t)dt$$

where f(t) is defined by a user-supplied subroutine, to specified accuracy.

2. Argument list

```
SUBROUTINE QA05AD(VAL,FUNC,A,B,AERR,RERR,LEVEL,ERROR,IFLAG)
```

VAL is a REAL*8 variable in which the value of I(a,b; f) is returned.

FUNC is the name of a user-supplied function subprogramme to evaluate f(t) for any value of t in the range [A,B]. Its only argument is the value of t, which is passed in REAL*8; the value is also returned in REAL*8.

A,B are REAL*8 input arguments giving the lower and upper limits of integration.

AERR are REAL*8 input arguments specifying the required accuracy as RERR max(AERR,RERR*ABS(VAL)).

LEVEL is an INTEGER*4 input argument specifying what printed output (if any) is required from the subroutine. LEVEL=1 specifies no output.

ERROR is a REAL*8 output argument in which the subroutine returns an estimated upper bound on the error achieved.

IFLAG is an INTEGER*4 output argument indicating what difficulties were encountered, if any. Values of IFLAG up to 3 indicate that VAL should be accepted as the result (subject to value of ERROR); the result may well be good even if IFLAG is 4 or 5.

APPENDIX X CALCOMP PLOTTER ROUTINES USED BY THE DATA REDUCTION PROGRAMME

The data reduction programme calls on various CALCOMP plotter subroutines. The purpose and arguments of these are described below. All dimensions given are in inches.

X.1 Subroutine PLOTS

1. Purpose

Initiates plotting of a logical segment.

2. Argument list

```
CALL PLOTS(IBUF,NO,NUM)
```

IBUF, NO, and NUM are INTEGER*4 dummy variables.

X.2 Subroutine ENDPLT

1. Purpose

Ends a logical segment. The new segment will start with the pen in the standard initial position and at the new logical origin.

2. Argument list

```
CALL ENDPLT
```

X.3 Subroutine ENDGR

1. Purpose

Ends plotting on the current device.

2. Argument list

```
CALL ENDGR
```

X.4 Subroutine PLOT

1. Purpose

Moves the pen to a specified position.

2. Argument list

```
CALL PLOT(X,Y,NPEN)
```

X,Y are REAL*4, and contain the logical coordinates of the next pen position.

NPEN is INTEGER*4 and is the signed sum of two positive integers, N and K.
If N=2, the pen is down during movement.
If N=3, the pen is down during movement.
Normally K=0.
If K=20, the logical origin is re-located at (X,Y) after movement.
If NPEN=999, the plot file is ended.

X.5 Subroutine SYMBOL

1. Purpose

Writes symbols and characters.

2. Argument list

```
CALL SYMBOL(X,Y,SIZE,TEXT,THETA,N)
```

X,Y are REAL*4, and define the logical coordinates of the lower left-hand corner of the first character to be drawn.

SIZE is REAL*4 and specifies the character height. It is recommended that this be a multiple of 0.07.

TEXT may be either REAL*4 or INTEGER*4, and contains a string of characters to be written.

THETA is REAL*4, and is the angle (in degrees) of orientation of the character string in TEXT with respect to the positive x axis.

N is INTEGER*4, and is the number of characters to be written.

X.6 Subroutine NUMBER

1. Purpose

Writes a floating point number.

2. Argument list

```
CALL NUMBER(X,Y,SIZE,FPN,THETA,N)
```

X, Y, SIZE and THETA are as for SYMBOL (see above).

FPN is REAL*4, and is the floating point number to be written.

N is INTEGER*4, and specifies the precision required. FPN is rounded to this precision.
If N is positive, it is the number of digits to the right of the decimal point.
If N is zero, the integer portion and decimal point are drawn.
If N is -1, only the integer portion is drawn.
If N is less than -1, ±N±-1 digits are truncated from the integer portion.

X.7 Subroutine LINE

1. Purpose

Draws a line through a set of coordinates.

2. Argument List

```
CALL LINE(X,Y,N,INC,LINTYP,INTEQ)
```

X,Y are REAL*4 arrays, and contain the x- and y-coordinates of the data points in the first N locations. X(N+2) contains a scaling factor, DELTAV (number of units per inch on the x-axis), and X(N+1) contains FIRSTV, a suitably rounded approximation to the first value to be plotted. The contents of Y(N+1) and Y(N+2) are similarly defined.

N is INTEGER*4, and is the number of data points in X or Y.

INC is INTEGER*4, and is the increment of successive data points in the X and Y arrays to be plotted.

LINTYP is INTEGER*4, and controls the type of line;
±LINTYP± is the frequency of plotted symbols. eg if ±LINTYP±=4 a symbol (specified by INTEQ) is plotted every 4th data point.
If LINTYP=0, no symbols are plotted.
If LINTYP is positive, a straight line connects the data points.
If LINTYP is negative, only symbols are drawn.

INTEQ is INTEGER*4, and specifies a special symbol to be drawn at the data points.

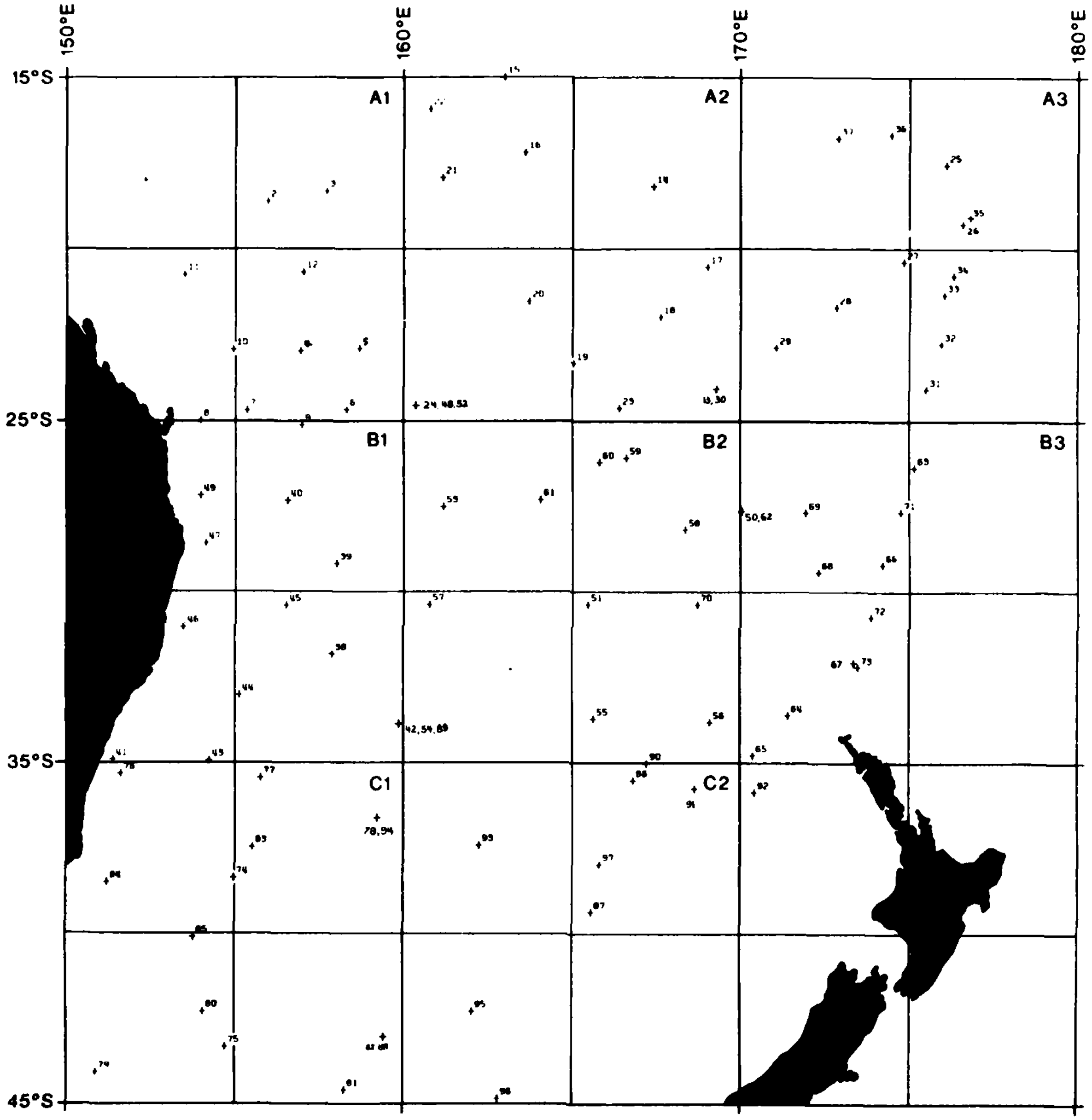


Figure 1. Locations of Nansen cast stations in the South-West Pacific Ocean

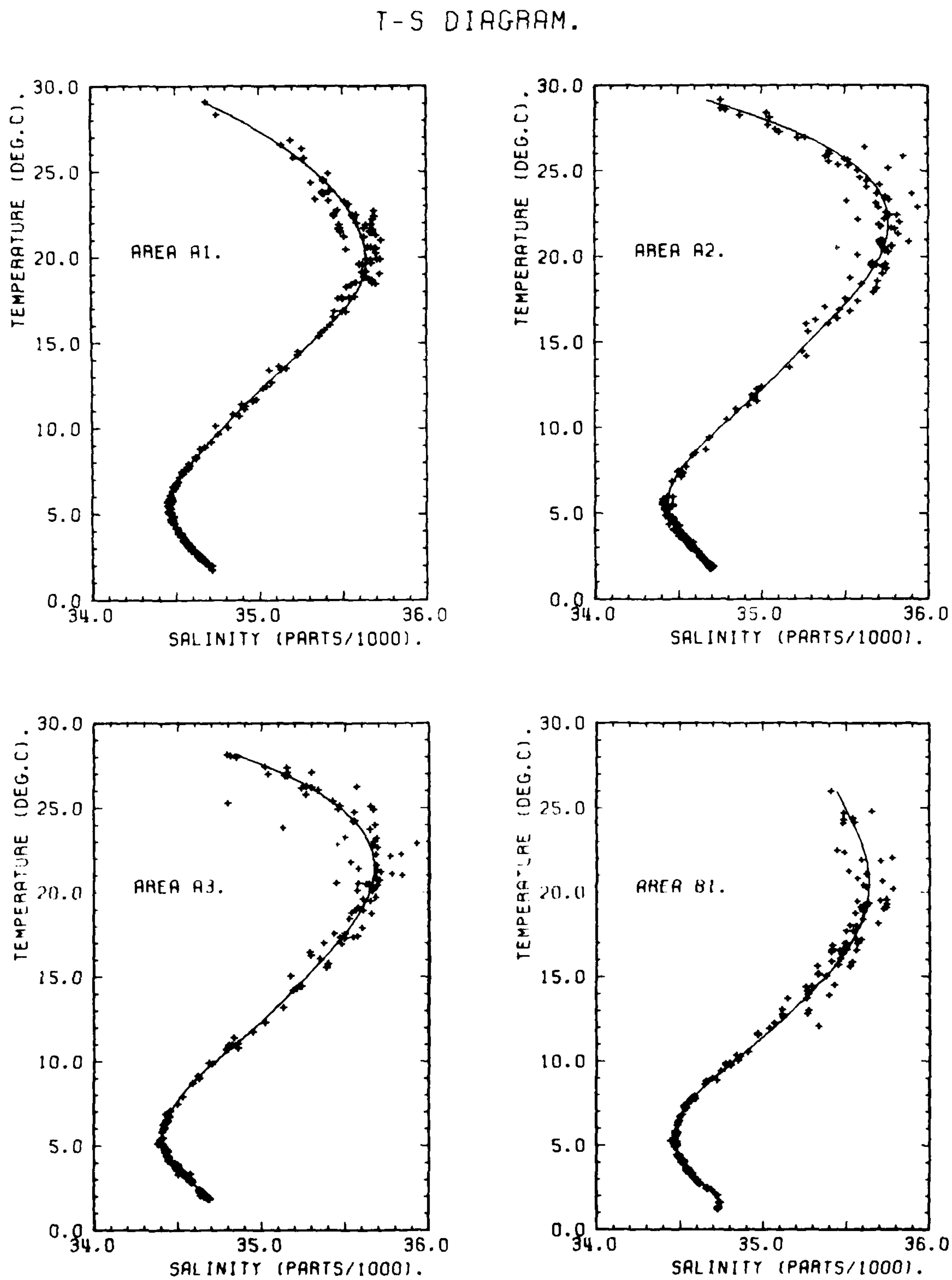


Figure 2. Temperature-salinity diagrams for the South-West Pacific Ocean constructed from historical Nansen cast data. The solid curves represent a least-squares cubic spline fit to the data (see text)

T-S DIAGRAM.

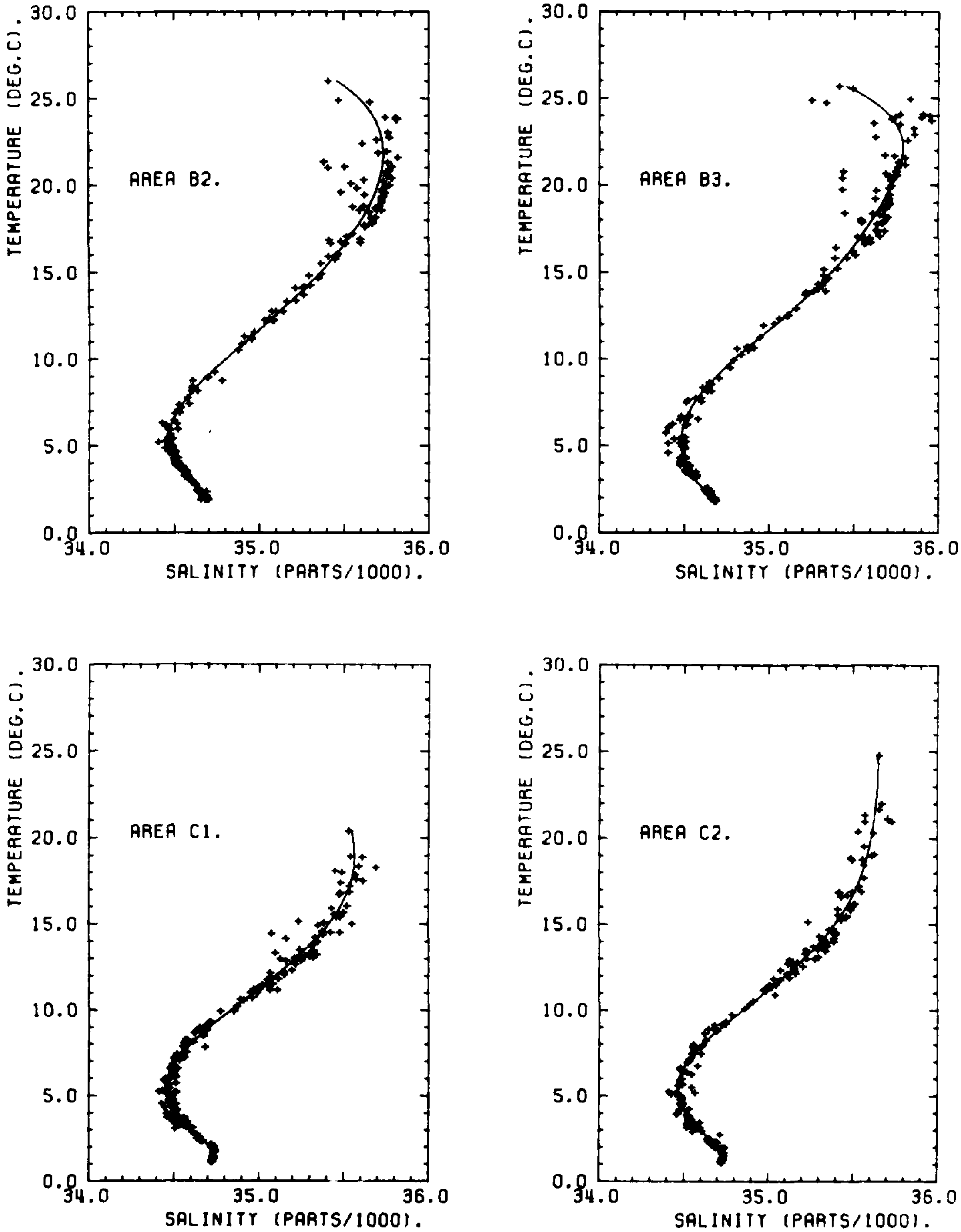


Figure 2(Contd.).

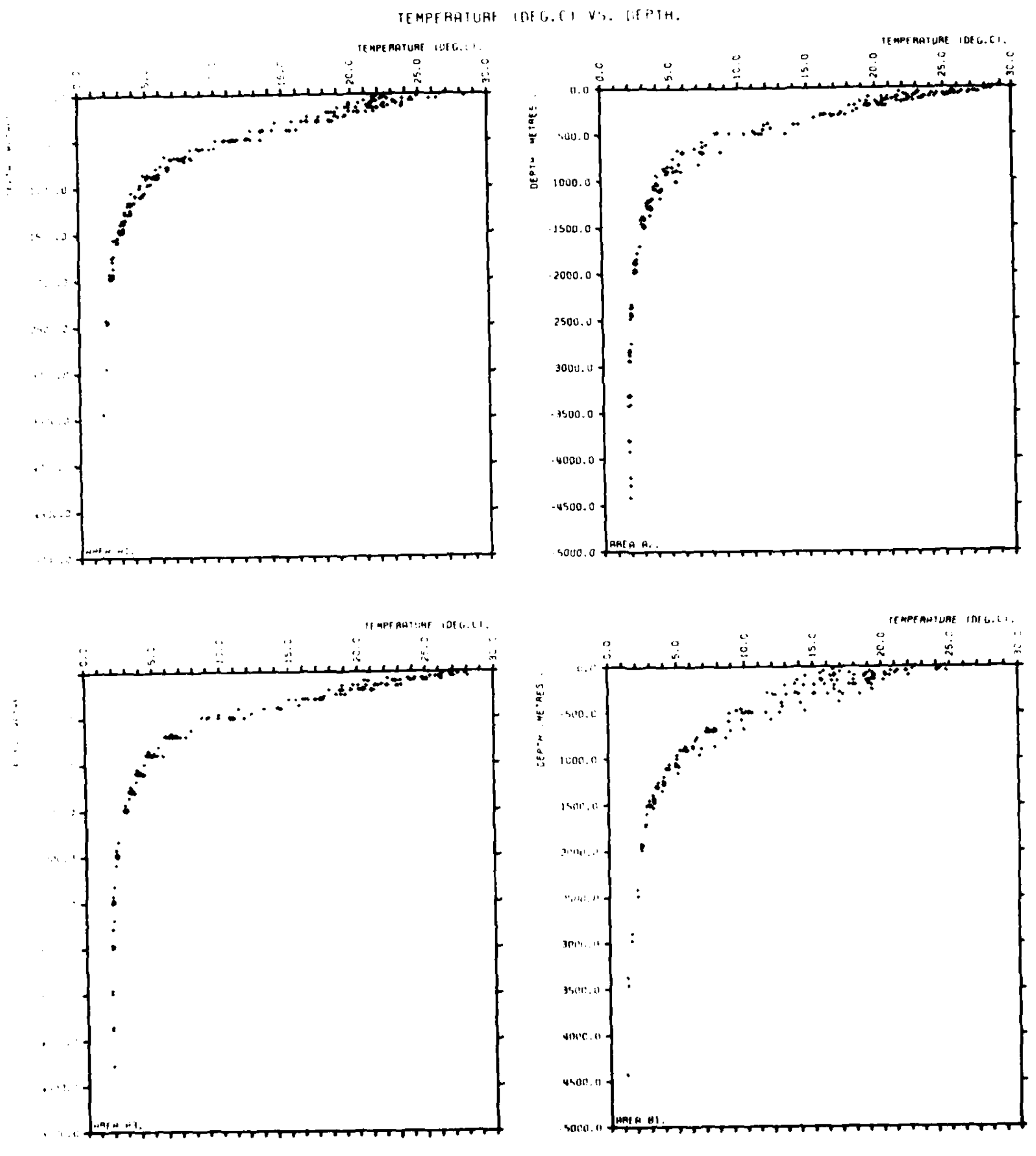


Figure 3. Temperature profiles constructed from Nansen casts made in the South-West Pacific Ocean. Points pertaining to the mixed layer have been edited out of the data base, and the data for each geographical area pooled

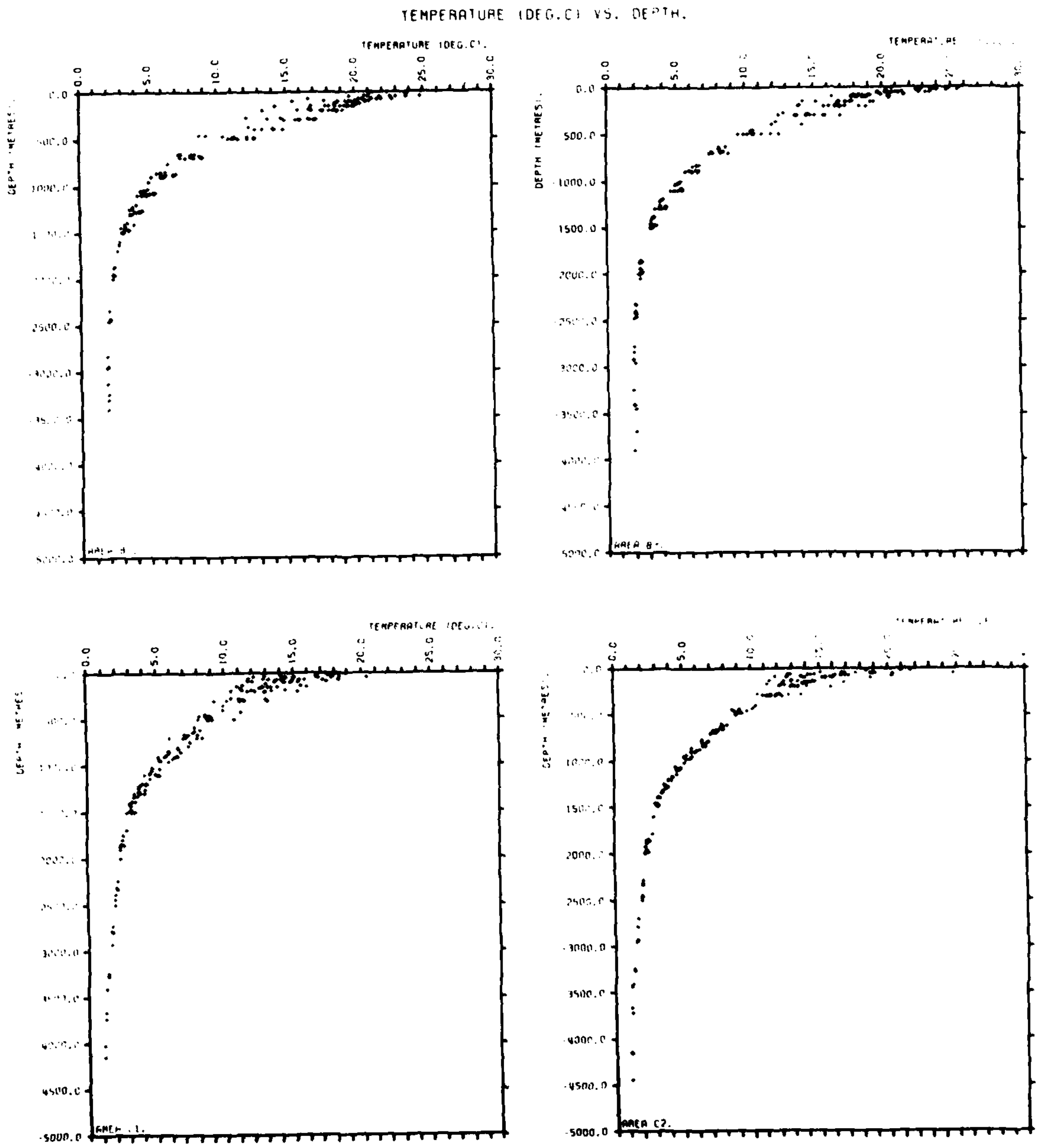


Figure 3(Contd.).

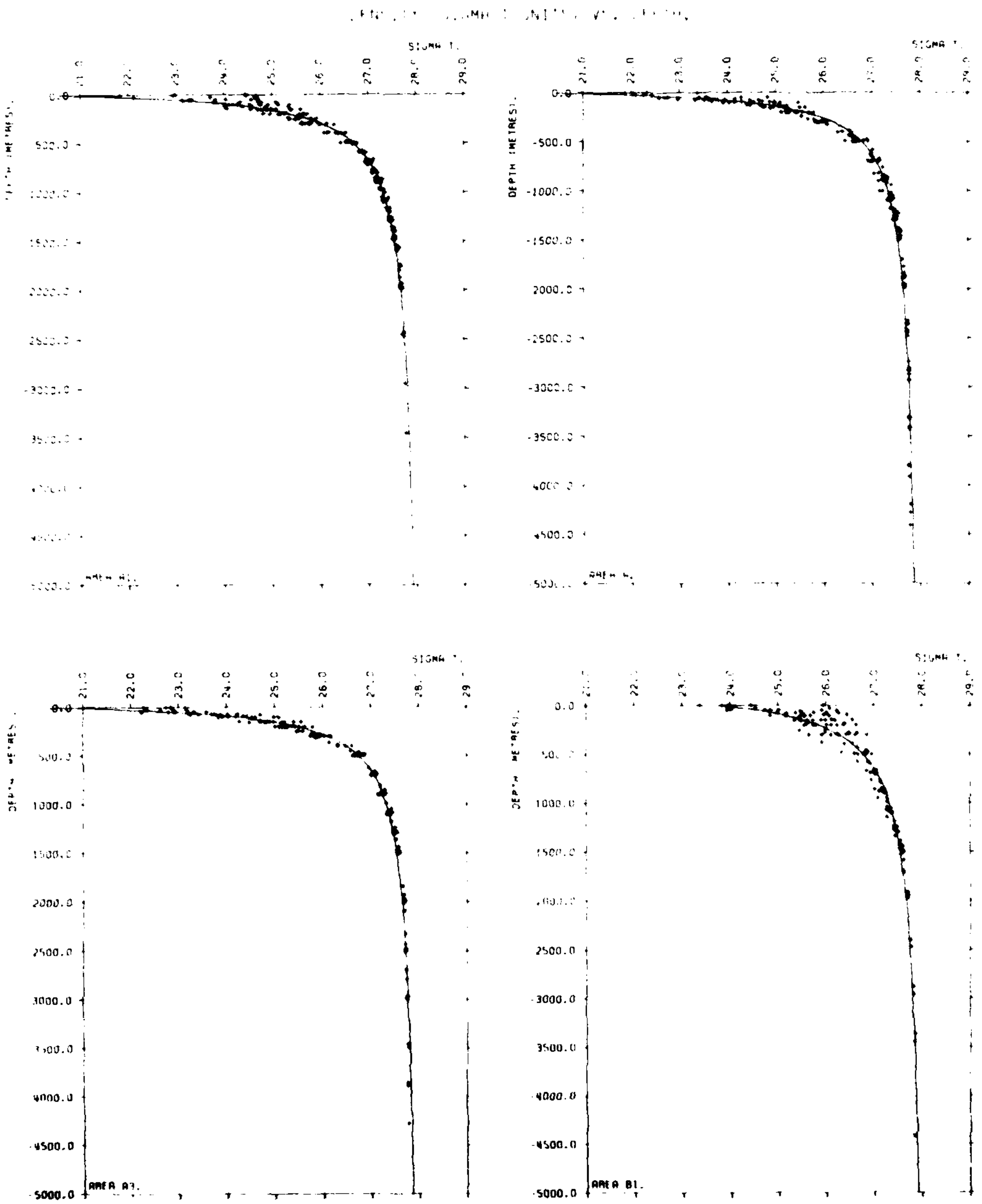


Figure 4. Profiles of σ_T versus depth constructed using the temperature profiles of figure 3 and corresponding salinity data. The solid curves represent a least-squares fit of equation (2)

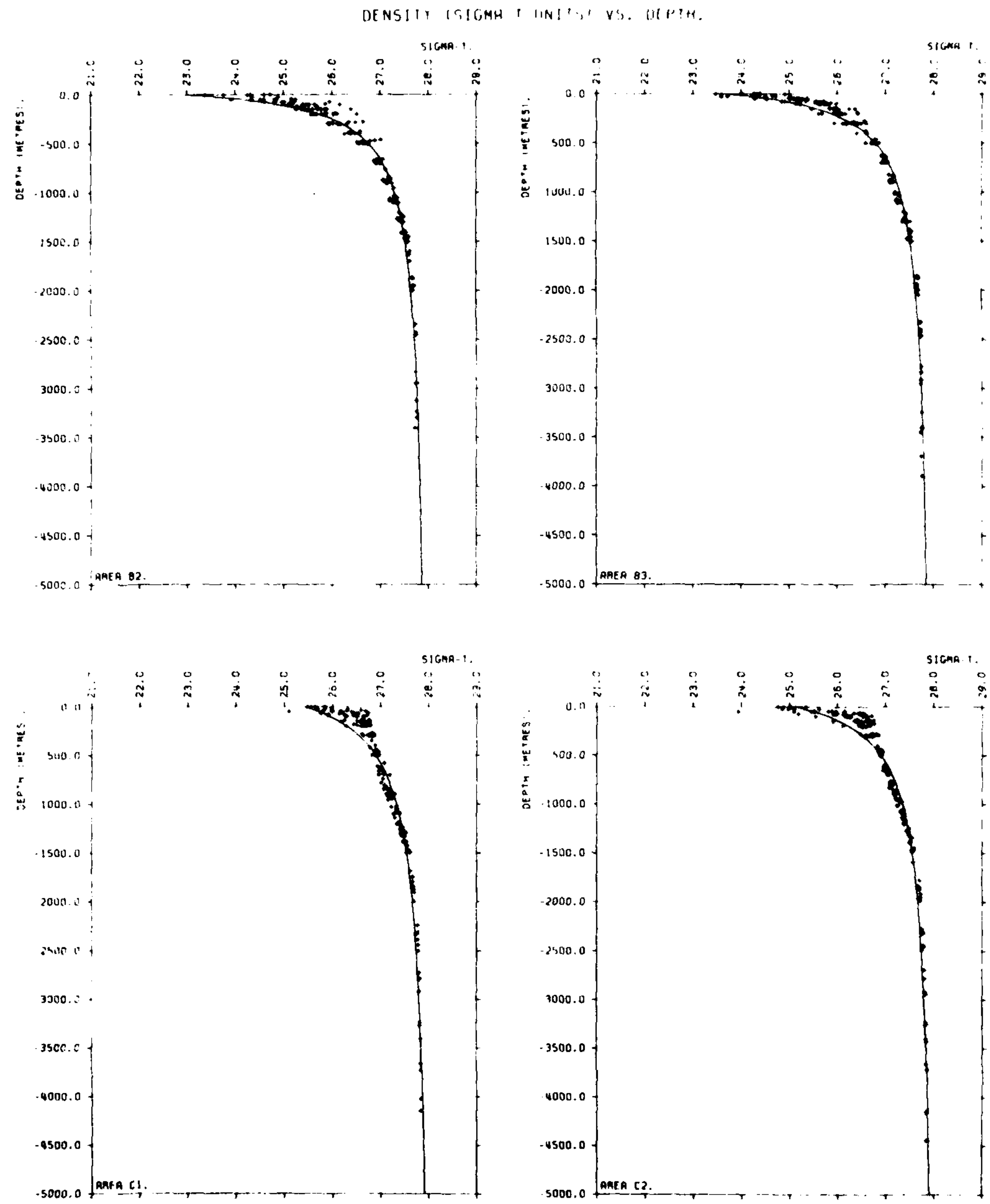


Figure 4(Contd.).

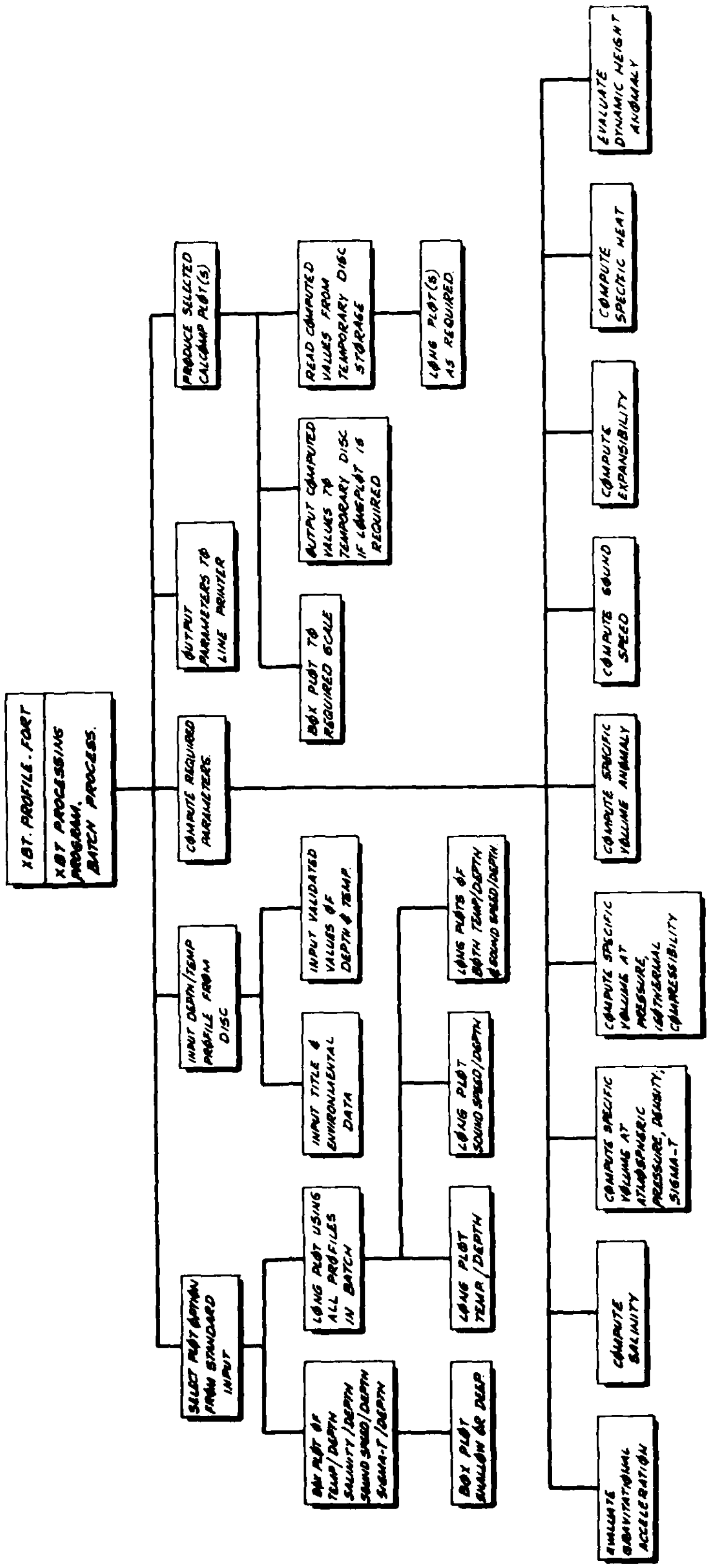
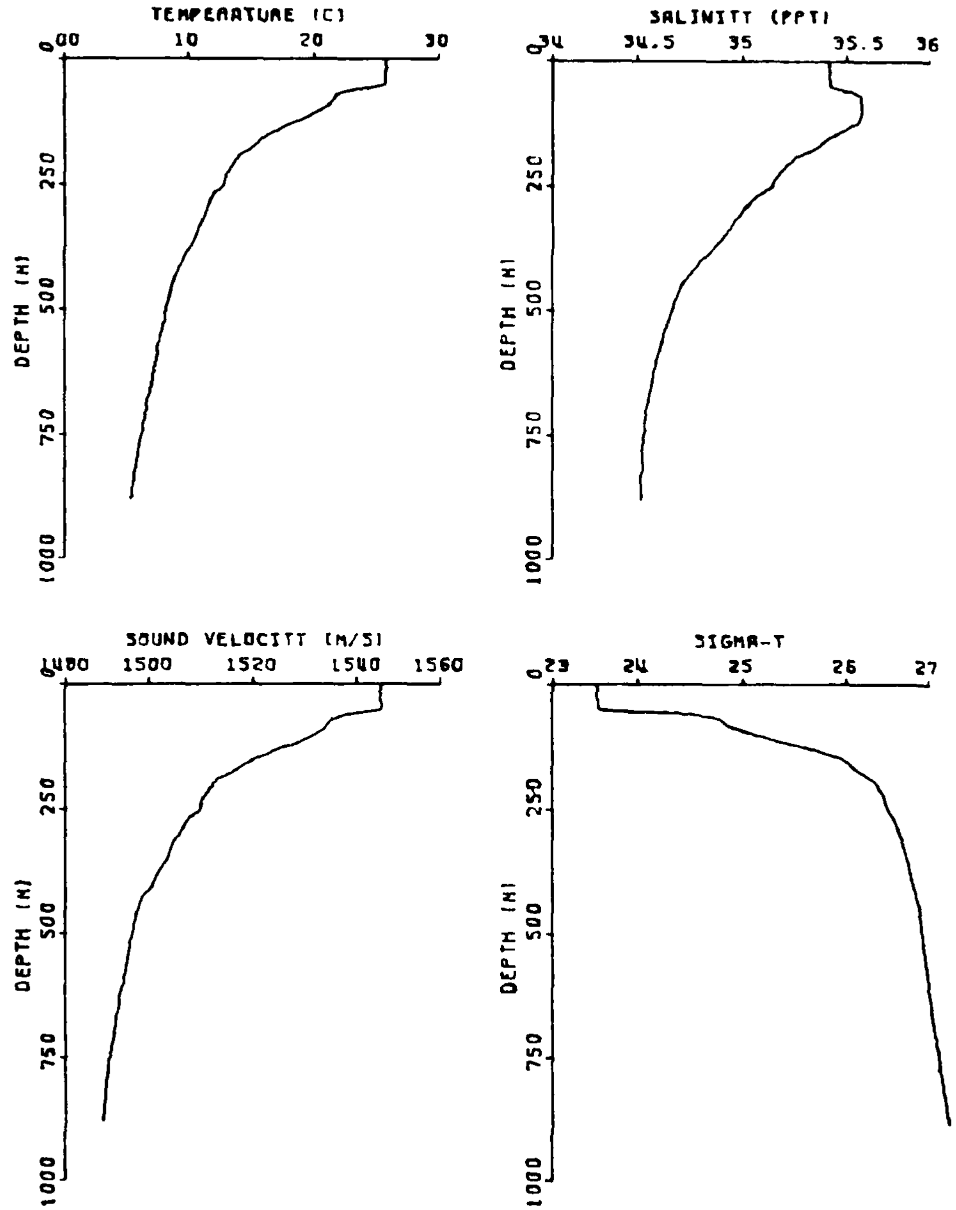


Figure 5. XBT programme organisation - an overview



CONSECUTIVE NO 2

Figure 6. A sample "fourplot"

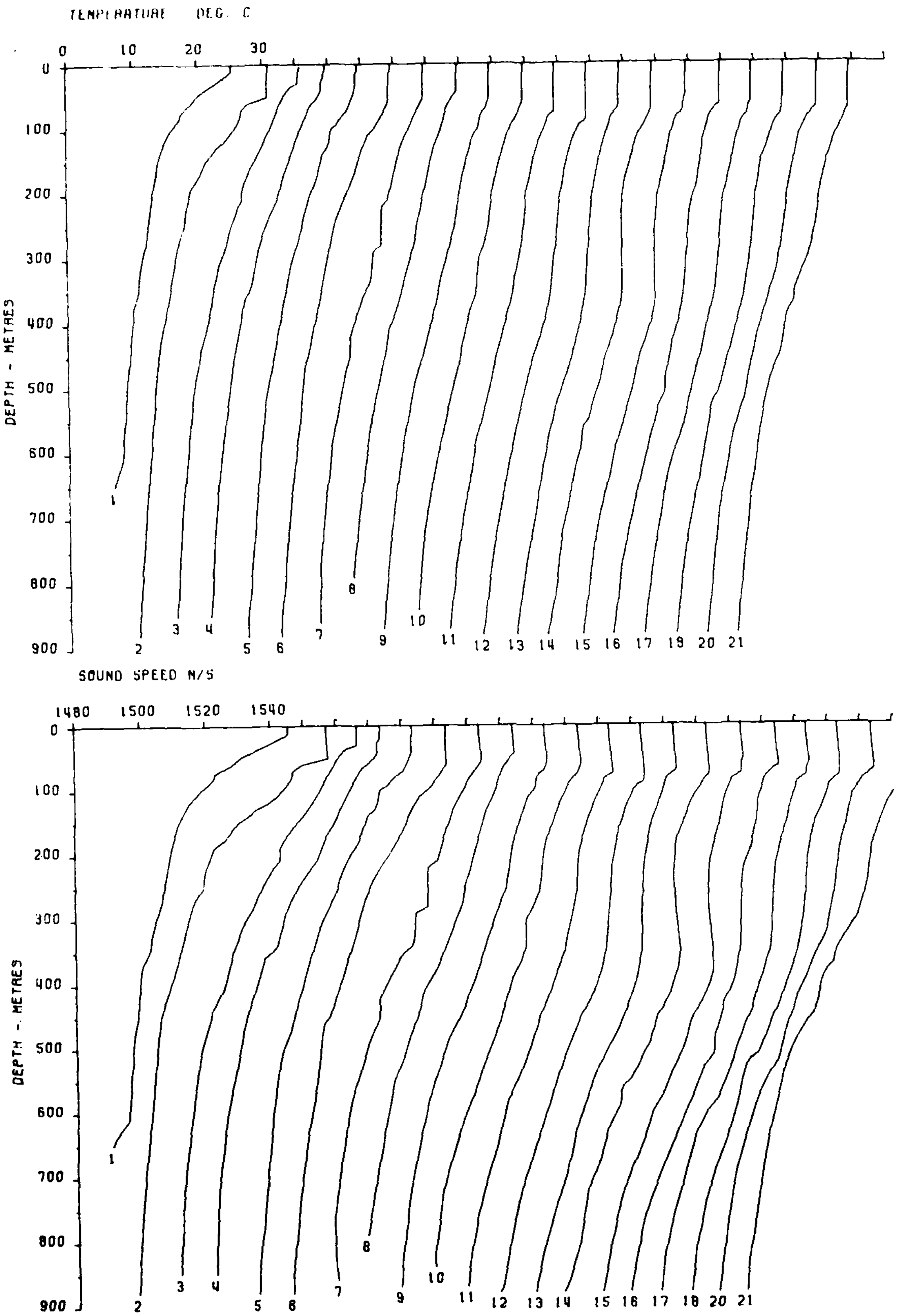


Figure 7. A sample "longplot"

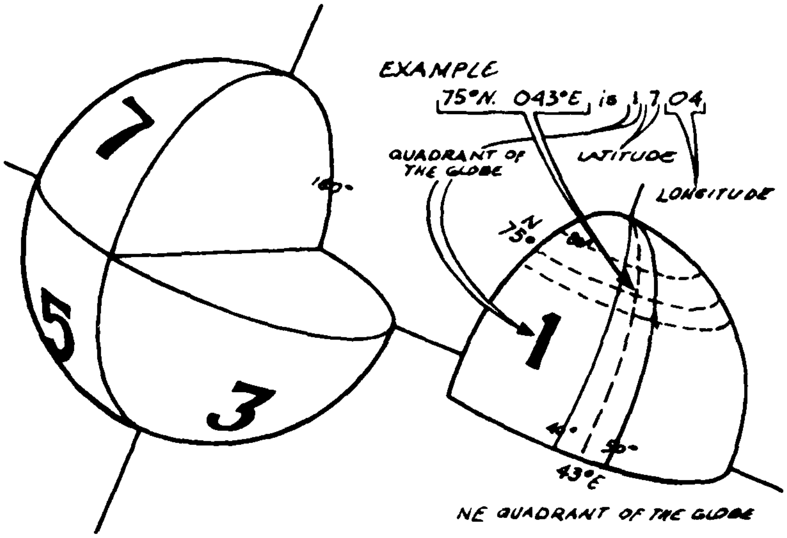


Figure 8. WMO Code 3333 quadrant and 10° square numbering system

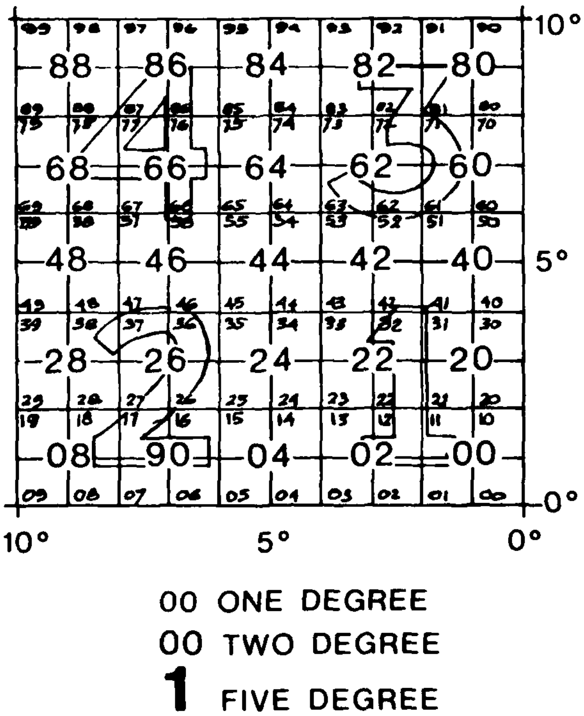


Figure 9. Modified Canadian 10° square subdivisions. All subdivisions of 10° squares are numbered identically regardless of quadrant of the globe

DISTRIBUTION

	Copy No.
EXTERNAL	
In United Kingdom	
Defence Science Representative, London	No Copy
British Lending Library Division, Boston Spa York	1
In United States of America	
Counsellor, Defence Science, Washington	No Copy
National Technical Information Services, Springfield VA 22151	2
Engineering Societies Library, New York NY 10017	3
Data Courier Inc, Louisville Ky 40202	4
In Malaysia	
The Director, Defence Research Centre, Malaysia	5
In Australia	
Chief Defence Scientist	6
Deputy Chief Defence Scientist	7
Superintendent, Science and Technology Programmes	8
Director, Joint Intelligence Organisation (DSTI)	9
Document Exchange Centre Defence Information Services Branch (for microfilming)	10
Document Exchange Centre Defence Information Services Branch for:	
United Kingdom, Ministry of Defence, Defence Research Information Centre (DRIC)	11
United States, Defense Technical Information Center	12 - 23
Canada, Department of National Defence, Defence Science Information Service	24
New Zealand, Ministry of Defence	25
Australian National Library	26

	Copy No.
Director General, Army Development (NSO), Russell Offices for ABCA Standardisation Officers	
UK ABCA representative, Canberra	27
US ABCA representative, Canberra	28
Canada ABCA representative, Canberra	29
NZ ABCA representative, Canberra	30
Director, Industry Development, Regional Office, Adelaide	31
Defence Library, Campbell Park	32
Library, Aeronautical Research Laboratories	33
Library, Material Research Laboratories	34
Navy Scientific Adviser	35
Air Force Scientific Adviser	36
Library, RAN Research Laboratory	37
(Attention: Superintendent)	38
(Attention: Dr C.S. Nilsson)	39
Australian Oceanographic Data Centre	
(Attention: Mr B.J. Searle)	40
(Attention: Lt Cdr D. Fraser)	41
CSIRO Division of Oceanography	
(Attention: Dr A.D. McEwan)	42
(Attention: Dr A.F. Pearce)	43
Australian Institute of Marine Science	
(Attention: Dr J.C. Andrews)	44
The Flinders University of South Australia	
(Attention: Prof G.W. Lennon)	45
The University of Newcastle	
(Attention: Prof R.A. Antonia)	46
C.J. Abell and Co Pty Ltd	
(Attention: Dr C.J. Abell)	47
WITHIN DRCS	
Chief Superintendent, Weapons Systems Research Laboratory	48
Superintendent, Weapon Systems Division	49
Superintendent, Communications and Electronic Engineering Division	50
Senior Principal Research Scientist, Marine Studies Composite	51

	Copy No.
Principal Officer, Underwater Detection Group	52
Principal Officer, Signal Processing and Classification Group	53
Principal Officer, Underwater Sonar Engineering Group	54
Principal Officer, Sea Experiments Group	55
Principal Officer, Sonar Trials Group	56
Dr D.A. Gray, Signal Processing and Classification Group	57
Dr G. Gartrell, ARDU	58
Dr A.L. Carpenter, Underwater Detection Group	59
Dr D.G. Cartwright, Surveillance Systems Group	60
Dr D.J. Kewley, Underwater Detection Group	61
DRCS Library	62 - 63
Authors	64 - 67
Spares	68 - 72

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1 DOCUMENT NUMBERS		2 SECURITY CLASSIFICATION	
AR Number:	AR-002-627	a. Complete Document:	Unclassified
Series Number:	WSRL-0229-TM	b. Title in Isolation:	Unclassified
Other Numbers:		c. Summary in Isolation:	Unclassified

3 TITLE

TECHNIQUES FOR THE ANALYSIS OF EXPENDABLE BATHYTHERMOGRAPH (XBT) DATA WITH APPLICATIONS TO THE SOUTH-WESTERN PACIFIC OCEAN

4 PERSONAL AUTHOR(S):

P.G. Marshallsay
S.M. Ball

5 DOCUMENT DATE:

September 1981

6 6.1 TOTAL NUMBER OF PAGES: 80

6.2 NUMBER OF REFERENCES: 25

7 7.1 CORPORATE AUTHOR(S):

Weapons Systems Research Laboratory

7.2 DOCUMENT SERIES AND NUMBER

Weapons Systems Research Laboratory 0229-TM

8 REFERENCE NUMBERS

a. Task:

b. Sponsoring Agency:

9 COST CODE:

10 IMPRINT (Publishing organisation)

Defence Research Centre Salisbury

11 COMPUTER PROGRAM(S) (Title(s) and language(s))

12 RELEASE LIMITATIONS (of the document):

Approved for Public Release

Security classification of this page: UNCLASSIFIED

Security classification of this page: UNCLASSIFIED

13 ANNOUNCEMENT LIMITATIONS (of the information on these pages):

No limitation

14 DESCRIPTORS:		15 COSATI CODES:
a. EJC Thesaurus Terms	Bathythermograph data Data processing Oceanography Sea water Temperature measurement Pacific Ocean	0810
b. Non-Thesaurus Terms	XBT	

16 SUMMARY OR ABSTRACT:
(if this is security classified, the announcement of this report will be similarly classified)

The expendable bathythermograph is a convenient and inexpensive tool for the measurement of ocean temperature structure. It does not measure salinity, but in many areas of the ocean it is reasonable to use standard temperature-salinity (T-S) curves to infer salinity from temperature measurements. T-S curves constructed from historical Nansen cast data are presented for 10° squares in the South-Western Pacific Ocean, covering the area from 15°S to 45°S, and from 150°E to 180°E. With a knowledge of both temperature and salinity structures a wide range of other parameters may be estimated, the most important of these being density, dynamic height and sound speed. Relationships for the computation of these and other properties of sea water are discussed, and computer programmes presented to calculate profiles of the relevant parameters from XBT data.

Security classification of this page: UNCLASSIFIED

The official documents produced by the Laboratories of the Defence Research Centre Salisbury are issued in one of five categories: Reports, Technical Reports, Technical Memoranda, Manuals and Specifications. The purpose of the latter two categories is self-evident, with the other three categories being used for the following purposes:

Reports	:	documents prepared for managerial purposes.
Technical Reports	:	records of scientific and technical work of a permanent value intended for other scientists and technologists working in the field.
Technical Memoranda	:	intended primarily for disseminating information within the DSTO. They are usually tentative in nature and reflect the personal views of the author.

FILMED

7-8